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Energy Management for Furnaces, Kilns, and Ovens

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This publication, the third in the EPIC Energy Management Series, provides a step-by-step procedure for determining the most effective energy cost reducing opportunities in the operation of furnaces, kilns, ovens and similar equipment. The assistance and advice of knowledgeable businessmen and competent engineers was solicited and used in developing the guide . . . a policy followed in each of the publications.

The EPIC Energy Management Series is an on-going series of publications designed to assist business leaders in developing and maintaining effective energy management programs, and will cover both technical and non-technical subjects. This series grew out of the original EPIC (Energy Conservation Program Guide for Industry and Commerce) published jointly by the National Bureau of Standards and the Federal Energy Administration.

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Energy Management for Furnaces, Kilns, and Ovens

NBS HANDBOOK 124

L. A. Wood, J. F. Ward,
and K. G. Kreider

Office of Energy Conservation
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

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Conversion Table to SI Units

This publication uses customary English units for the convenience of engineers and others who use them habitually. The table below is for the reader interested in conversion to SI units. For additional information see:

(1) NBS LC1078, Dec., 1976, "The Metric System of Measurement".

(2) Z210.1–1976, "American National Standard for Metric Practice."

Quantity	To convert from	To	Multiply by
Length	inch	m (meter)	2.540×10^{-2}
	foot	m	3.048×10^{-1}
	mile	m	1.609×10^{3}
Area	in^2	m^2	6.452×10^{-4}
	ft^2	m^2	9.290×10^{-2}
Volume	in^3	m^3	1.639×10^{-5}
	ft^3	m^3	2.832×10^{-2}
	gallon	m^3	3.785×10^{-3}
Temperature	°F	°C	$t_{\circ C}=(t_{\circ F}-32)/1.8$
T. difference	$\Delta t_{\circ F}$	K	$\Delta T_K=\Delta t_{\circ F}/1.8$
Mass	pound	kg	4.536×10^{-1}
	ounce	kg	2.835×10^{-2}
Pressure	psi	Pa	6.895×10^{3}
	in H_2O	Pa	2.488×10^{2}
	in Hg	Pa	3.386×10^{3}
	mmHg	Pa	1.333×10^{2}
Energy	Btu	J	1.055×10^{3}
	MBtu	J	1.055×10^{9}
	kWh	J	3.600×10^{6}
	ft·lbf	J	1.356×10^{0}
	kilocalorie	J	4.184×10^{3}
Power	Btu/h	W	2.931×10^{-1}
	hp	W	7.457×10^{2}
Flow	gal/min	m^3/s	6.309×10^{-5}
	$\mathrm{ft}^3/\mathrm{min}$	m^3/s	4.719×10^{-4}
Density	$\mathrm{lb}/\mathrm{ft}^3$	kg/m^3	1.602×10^{1}
	lb/gal	kg/m^3	1.198×10^{2}
Heat Capacity	Btu/(lb·°F)	J/(kg·K)	4.187×10^{3}
	$\mathrm{Btu}/(\mathrm{ft}^3\cdot{}^\circ\mathrm{F})$	$\mathrm{J}/(\mathrm{m}^3\cdot\mathrm{K})$	6.707×10^{4}
Conductivity	$\mathrm{Btu}\cdot\mathrm{in}(\mathrm{h}\cdot\mathrm{ft}^2\cdot{}^\circ\mathrm{F})$	W/(m·K)	1.442×10^{-1}
Heat of Combustion	Btu/gal	J/m^3	2.787×10^{5}
	Btu/lb	J/kg	2.327×10^{3}
	$\mathrm{Btu}/\mathrm{ft}^3$	J/m^3	3.728×10^{4}
Barrel (Petroleum)	42 gal	m^3	1.590×10^{-1}

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Energy Management for Furnaces, Kilns, and Ovens

L.A. Wood, J.F. Ward, and K.G. Kreider

This handbook, part of the EPIC Energy Management Series, is directed to the user of direct-fired heating equipment in light industry. Other publications in this series outline steps to plan and establish an energy conservation program in a business or industry. This handbook is a guide to making decisions as to just what actions are appropriate and effective for energy savings in equipment such as furnaces, kilns, and ovens. The major technique described is the heat balance. Examples of heat balances are used to identify energy losses on a batch furnace, a continuous paint dryer oven, and a slot forging furnace. Typical energy conservation opportunities in combustion control, insulation, etc. are discussed. Simplified methods of calculation and measurement are given. Benefit/cost analysis and the time required to recoup investment are described as means of evaluating energy-saving investments.

Key words: Energy conservation, industrial; furnaces, energy conservation; heat balance; industrial energy conservation; kilns, energy conservation; ovens, energy conservation.

1. Introduction

Eleven percent of the nation's energy is used by industry for "direct heating," according to Department of Commerce data. This does not include indirect heating by the use of steam. The majority of this direct heating energy is used by large plants in heavy industry, such as primary metals, oil refining, or cement manufacturing. However, much is used by smaller organizations to heat treat metal parts, fire ceramics, dry paint, bake bread, and many other heating operations. It is to these small organizations that this guidebook is addressed. The guidebook is intended to describe how one can save energy in furnaces, kilns, and ovens, and it is written so that an engineering degree is not needed to use the information.

The need for good energy management has been recognized in this era of increasing energy costs. Numerous publications are available to assist a plant manager in improving his fuel efficiency. The National Bureau of Standards has made available the Energy Conservation Program Guide for Industry and Commerce [1].[1] This handbook points out that a good energy conservation program consists of several steps:

- ○ Plan and organize a program, with a firm commitment to energy saving.
- ○ Conduct energy audits to determine the total energy costs and find where the large uses of energy occur.
- ○ Take actions to conserve energy.
- ○ Continue an active energy conservation program.

In many energy-intensive organizations, the energy audit will quite frequently show that much of the energy is going to one or more pieces of direct fired equipment such as a furnace, kiln, dryer, etc. The success of an energy management program will then depend on the decisions as to just what steps are most appropriate for energy savings in these pieces of equipment.

Making such decisions, and making them intelligently, is not something that can be done by a simple rule-of-thumb. One can, and should, refer to check-lists which describe the possible options for increasing the energy efficiency of heating equipment, but nothing in such lists indicates the relative importance of the various check-list items. In other words, in one installation the most important first step may be adjusting the air to fuel ratio, in another the lack of insulation may be the important factor, and in a third it is possible that no major energy saving program is justified.

---

[1] Figures in brackets indicate the literature references at the end of this handbook.

The tool which will enable one to estimate the amount of energy which might be conserved and will point out the best ways of doing it is the heat balance. It will permit the translation of measurement and calculations to dollars of fuel savings.

2. Heat Balances

2.1. A General Description

A heat balance is simply a listing of the energy in all forms that enters a system over a given period of time—the input—and a similar listing of the energy that leaves—the output. Since energy is neither created nor destroyed, the input and the output must be equal.

For an energy management program, a heat balance on a critical piece of equipment serves several purposes:

○ It will show how much of the energy input was actually used for the intended purpose, e.g., to heat the product, to drive off water, etc. This figure may be used to calculate the energy efficiency of the system. The efficiency in practice is often as low as 2 to 5 percent.

○ It will show how much of the energy is lost to the atmosphere or perhaps to a cooling pond. This, of course, represents energy savings that are theoretically possible.

○ The heat balance, reasonably well done, will show also how the heat loss occurs. Some heat will be carried out with the product, some lost up the stack, some radiated to the surroundings from the furnace walls, etc. This information furnishes clues as to where one should look for the most important energy conservation possibilities.

○ Most important of all, a heat balance is by far the best tool which one can use to estimate the energy and cost savings which can be achieved by some change in process or equipment that is proposed as an energy saving investment. It will also enable one to identify the most valuable of several conservation proposals.

As an illustration, consider a simple system for the job of heating a pint of water from 72 °F to boiling. If we heat the water in a heavy cast iron skillet on the large burner of a kitchen stove, tests show the job requires two cubic feet of gas or 2000 British thermal units (Btu) to do the job. This 2000 Btu is the input energy to the system.

The system output is in three parts. The energy needed to heat the water from 72 to 212 °F can be calculated at 140 Btu, and the energy necessary to heat the 3.5 pound skillet is about 60 Btu. The remainder, some 1800 Btu, must be the energy in the hot combustion products which was lost to the atmosphere of the kitchen. The efficiency of this system is 140 Btu divided by 2000 Btu, or 7 percent.

A more efficient system than the above would use a glass laboratory beaker as the container and a small electrical immersion heater as the energy source. This time, the heat to the container would be 10 Btu, and the loss to the surrounding air about 50 Btu, requiring an electrical energy input of only 200 Btu. Assuming that about 600 Btu of fossil fuel was required to generate this electricity, the efficiency has been increased to 140 Btu divided by 600 Btu, or 23 percent.

The important point of the above illustration is that the heat balance permitted the identification of the most important of the energy losses, namely the large amount of energy escaping around the skillet. Designers have improved the energy efficiency of modern electric coffee makers by reducing this loss.

The next three sections of this guide show industrial uses of the heat balance as a conservation tool. One example will show how it may be used on a batch heat treating furnace, another its use on a continuous paint drying oven, and the third lists the results of a conservation project.

The first example, the batch furnace (section 2.2), represents the simplest type of an industrial heat balance; it requires the minimum number of measurements and calculations.

The second example, the drying oven (sec. 2.3), was chosen as representing a considerably more complex problem. It is necessary, for instance, to measure the velocity of a stream of air or exhaust gas and to calculate its energy content in order to determine the heat loss from the stack.

The third example (sec. 2.4) gives the measured results obtained in an energy saving project on a forging furnace, and shows that the actual savings achievable are similar in magnitude to those estimated in sections 2.2 and 2.3.

Subsequent sections of this guide describe some methods of measurement and the simple calculations needed. Reference [2] is one of several good sources for a detailed discussion of heat balances.

2.2. Heat Balance on a Batch Furnace

An oil fired furnace heats one-ton batches of steel to 2000 °F for a forging operation. The furnace burns

95 gallons of No. 2 fuel oil during each two-hour cycle. This oil yields 13.3 MBtu (13 300 000 Btu). The stack temperature is 2100 °F, and an analysis of the flue gas shows an oxygen content of 11 percent, meaning that the furnace uses 100 percent excess air, twice the amount of air theoretically needed to completely burn the fuel.

The heat flow for this situation is illustrated by figure 1. (Measurement methods and calculations are discussed in sections 4 and 5 of this guide.)

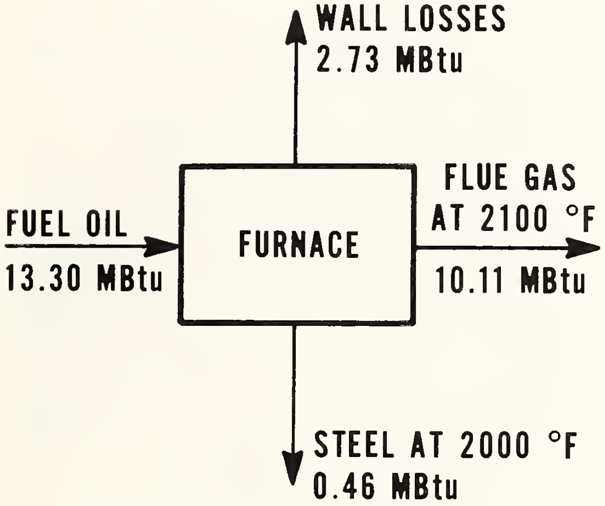

Figure 1. *Batch fired furnace (first heat balance).*

For simplicity, this example considers only the fuel used while actually heating a batch of steel. It ignores the fuel used to heat up a cold furnace, and to keep it hot while unloading one batch and loading the next. Because of this, actual savings due to a conservation project will be greater than those estimated in this example. Any change which saves energy during operation will also save some energy during warm up and during idling.

The only energy input to this system is the burning fuel oil. At an energy content of 140 000 Btu per gallon for No. 2 oil,

$$\underline{\text{Heat Input}} = 140\,000 \text{ Btu/gal} \times 95 \text{ gal} = \underline{13.30 \text{ MBtu.}}$$

This same quantity of energy must also leave the furnace during each cycle; it does so in three forms:

(1) The heat content of the steel is the weight of the steel times its temperature increase times its specific heat of 0.12 Btu/lb·°F. If the steel enters the furnace at 100 °F, then the energy removed from the furnace by a heated one-ton batch will be:

$$\underline{\text{Heat in steel}} = 2000 \text{ lb} \times (2000 - 100)\ °\text{F} \times 0.12 \text{ Btu/lb}\cdot°\text{F} = 456\,000 \text{ Btu, or } \underline{0.46 \text{ MBtu.}}$$

(2) The stack loss represents the energy escaping in the hot flue gas. Referring to figure 2, note that at a stack temperature of 2100 °F, and with 100 percent excess air, the stack loss is 76 percent of the fuel burned.

$$\underline{\text{Stack loss}} = 13.30 \text{ MBtu} \times 0.76 = \underline{10.11 \text{ MBtu.}}$$

(3) Conduction and radiation losses from the furnace walls and roof must make up the remainder of the energy output (refer to fig. 1).

$$\underline{\text{Wall losses}} = 13.30 - (0.46 + 10.11) = \underline{2.73 \text{ MBtu.}}$$

$$\underline{\text{Output}} = 0.46 + 10.11 + 2.73 = \underline{13.30 \text{ MBtu per cycle.}}$$

It is evident in this *first heat balance* that most (76 percent) of the energy is wasted up the exhaust stack. Looking again at figure 2, one can observe that the stack loss is least when the amount of combustion air is precisely the amount required to completely burn the fuel. If large amounts of excess air are supplied, much of the energy of the fuel is used to heat the air, and the stack loss becomes very large. Conversely, of course, if insufficient air is supplied the fuel will not be completely burned and energy will again be wasted. A reasonable quantity of excess air when burning fuel oil is about 20 percent, or when burning natural gas about 5 to 10 percent.

Excess air can be reduced by adjusting the burners, by throttling the air inlets, and by repairing cracks, holes, and ill-fitting doors. The stack damper should also be adjusted to maintain a very slight positive pressure in the fire-box to prevent the infiltration of unwanted air. The goal of 20 percent excess air is reached when, as discussed in section 4, the flue gas analysis shows approximately 3.5 percent oxygen and approximately 13 percent carbon dioxide.

At 20 percent excess air, figure 2 shows that the stack loss is only 46 percent of the fuel energy instead of the original 76 percent. The energy absorbed by the steel remains at 0.46 MBtu per cycle, and the loss from the walls and roof is still 2.73 MBtu. This total, 2.73 + 0.46 = 3.19 MBtu, is now 54 percent of the total input (100% − 46% = 54%). The total fuel energy needed per cycle is therefore:

Input = 3.19 MBtu/0.54 = 5.91 MBtu.

With this input, we can make a *second heat balance:*

Input	Output	
5.91 MBtu	Steel	0.46 MBtu
(42.2 gal of oil)	Stack	2.72 MBtu
	Walls	2.73 MBtu
	Total	5.91 MBtu

In the second heat balance, even after adjusting the excess air to the practical minimum, energy is being wasted up the stack at the rate of 2.72 MBtu per cycle, or at 500 cycles per year, 1360 MBtu per year. With oil at 35¢ per gallon, this is a dollar loss of $3400 per year.

Some of this heat can be recovered by passing the flue gas through a heat exchanger, or through a waste heat boiler. The recovered heat can be used for a variety of purposes; following are some of those frequently suggested.

(1) Make steam for process use, for electrical power generation, or for space heating.

(2) Heat water for processing or for space heating.

(3) Preheat combustion air for the furnace.

(4) Preheat the product entering the furnace.

(5) Heat air for space heating.

The best use for the recovered heat depends on the process and the particular plant conditions. In this case, with a batch furnace and possibly a rather uneven schedule, preheating the combustion air might be the best use. Figure 3 shows the heat flow with such an arrangement as a *third heat balance.* The numbers are MBtu of energy for a two hour furnace cycle.

To estimate the fuel usage under these conditions, consider the entire diagram as a single system with one heat input (the air at 100 °F is considered to carry no heat), and three outputs. Two of the outputs are the heat in the steel and the conduction losses. The sum of these outputs is 3.19 MBtu as in the second heat balance. The third output is the waste flue gas at 1100 °F. (Since the mass of flue gas is approximately equal to the mass of combustion air, it is reasonable to estimate that if the air is heated by 1000 °F, the flue gas will be cooled by the same amount.)

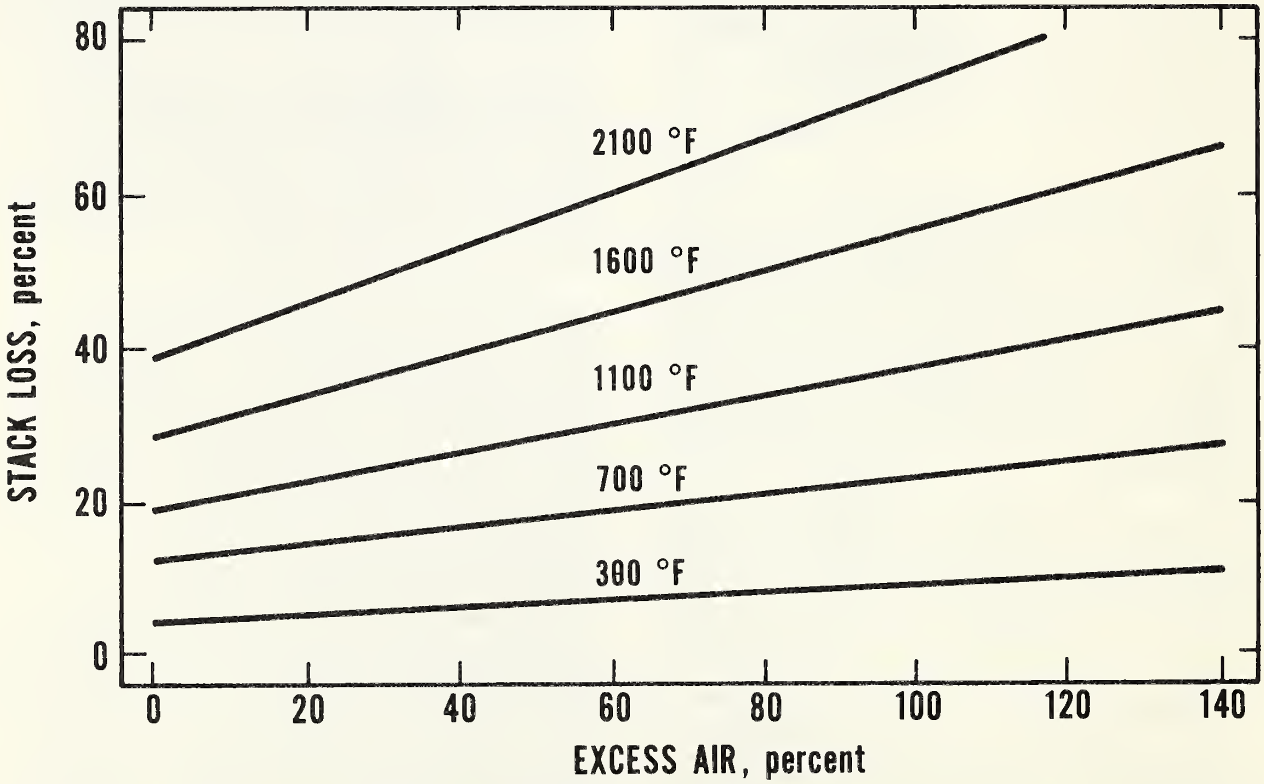

Figure 2. *Stack loss (wasted fuel energy in stack gases) versus excess air, at various stack gas temperatures.*

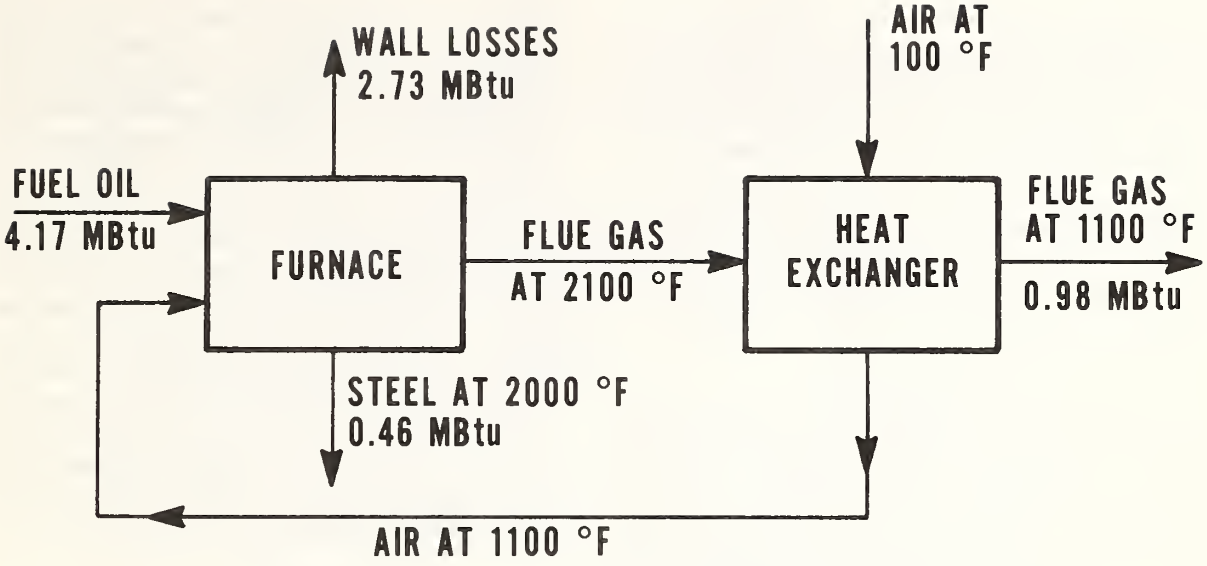

FIGURE 3. *Batch furnace with preheated combustion air (third heat balance).*

According to figure 2, at 20 percent excess air and a stack temperature of 1100 °F, the stack loss is 23.5 percent of the fuel fired. The other two outputs, the 3.19 MBtu for conduction losses and for heat in the hot steel, must therefore amount to 100 percent − 23.5 percent = 76.5 percent of the fuel. Under this condition,

$$\underline{\text{Fuel energy}} = 3.19 \times 1/0.765 = \underline{4.17\text{ MBtu per cycle.}}$$

$$\underline{\text{Stack loss}} = 4.17 \times 0.235 = \underline{0.98\text{ MBtu per cycle.}}$$

At this point, the largest energy loss in the system is the 2.73 MBtu lost by conduction and radiation through the walls and roof of the furnace.

If we further assume that suitable repair or addition to the insulation can reduce this loss to 1.90 MBtu per cycle, a *fourth heat balance* performed in a similar manner shows that this will reduce the fuel input to 3.08, and the stack loss to 0.72 MBtu per cycle. Table 1 summarizes the results of these heat balance analyses of the furnace system.

Assuming a production rate in this furnace of 500 cycles per year, and an average fuel oil cost of 35¢ per gallon, the yearly cost of energy under the four different conditions is as follows:

(1) Original condition	$16 600
(2) Reduce excess air	$ 7 400
(3) Preheat air	$ 5 200
(4) Add insulation	$ 3 800

Note that these changes to save money were not all of equal value. By far the most important was the reduction of excess air from 100 percent to 20 percent. This single change saves $9200 per year, and the capital cost involved would be quite minor.

The next change, that of preheating the air, produced a smaller saving of $2200. The cost of a heat exchanger, duct work, and probable burner modifications will vary widely for different installations. If in

TABLE 1. *Batch furnace heat balances*

Condition	Energy per two-hour cycle				Efficiency
	Input	Stack loss	Conduction loss	Heat in steel	
	MBtu	MBtu	MBtu	MBtu	Percent
(1) Original system	13.30	10.11	2.73	0.46	3.5
(2) Reduce excess air	5.91	2.72	2.73	0.46	7.8
(3) Preheat air	4.17	0.98	2.73	0.46	11.0
(4) Add insulation	3.08	0.72	1.90	0.46	14.9

this case the cost were $2500, it would be a very attractive proposition; a quotation of $10 000 would require some rather careful analysis before making the investment. If one assumes a continuing increase in energy costs, however, even the latter figure might be within reason.

The third step, adding insulation, saved $1400. The cost could be low if it consisted of the simple addition of some bats or blankets of ceramic fiber on the inside of the walls and roof, or higher if it required rebuilding of the entire furnace lining.

It is evident that there is no simple rule-of-thumb that one can use to decide which energy saving steps to take or in what order to take them. An intelligent decision requires a reasonable knowledge of the heat balance and an estimate of the net savings possible for each proposed step. One must consider potential fuel costs and the cost of capital investment in estimating net savings.

2.3. Heat Balance on a Paint Dryer

Some continuous kilns or ovens, such as those used for brazing, annealing, sintering, etc., may be treated in much the same fashion as a batch furnace when estimating an energy balance. It is only necessary to translate all energy units into Btu per hour or per minute instead of Btu per batch or cycle. The principles of energy management in such kilns are exactly the same as those discussed in section 2.2: maintain the minimum practical excess air, insulate properly, and recover waste heat whenever possible.

Other kilns, such as those used for drying a product containing water or an organic solvent, may be more complex. For example, the paint drying oven to be discussed below must use so much air to dilute the combustible solvent vapors that the stack gas carries almost 1000 percent excess air. In this case it is not practical to get an accurate analysis of the stack gas, and a measurement of the air flow rate is necessary in order to estimate a heat balance. The following sections 4 and 5 suggest methods of measurement and calculation that can be used.

As an example of the heat balance applied to a continuous operation, consider a conventional continuous paint drying oven which is fed with 600 pounds of wet paint on 10 000 pounds of steel per hour. The paint is composed of 290 pounds of solvent and 310 pounds of paint solids. The air in the oven is heated to 500 °F with natural gas, which evaporates the paint solvent (1190 cubic feet of vapor), and raises the temperature of the steel to 400 °F. A large amount of excess air is required in order to prevent the formation of an explosive atmosphere of air and solvent vapor; the usual requirement is 10 000 cubic feet (cf) of excess air per gallon (about 7.25 lb) of solvent evaporated. Air pollution regulations state that the hydrocarbon vapors in the oven exhaust cannot be discharged directly into the atmosphere. The exhaust, therefore, is led into an incinerator where more natural gas is burned to raise the temperature from 500 °F to 1600 °F. At this temperature the hydrocarbons are all oxidized to carbon dioxide and water, and may safely be sent up the stack. A diagram of the system is shown in figure 4. All of the calculations for this example are shown in section 4 with only summaries used here for clarity.

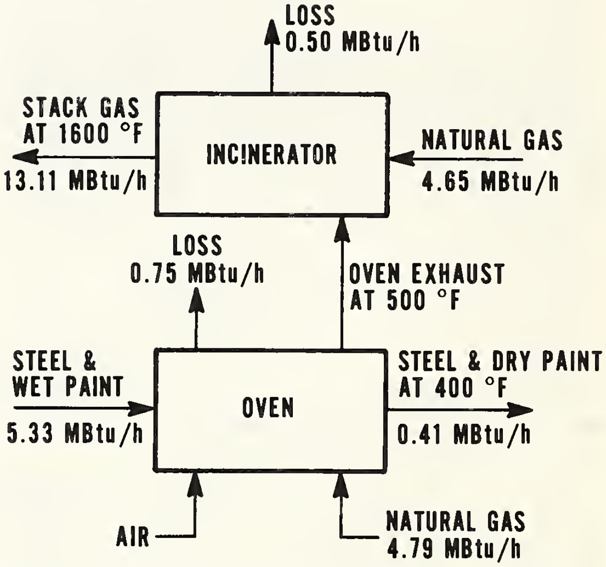

FIGURE 4. *Conventional paint drying oven and fume incinerator.*

The heat balance for a conventional paint dryer operated as in figure 4 is as follows:

INPUT

Natural gas to oven	4.79 MBtu/h
Natural gas to incinerator	4.65 MBtu/h
Solvent vapors [2]	5.33 MBtu/h
Total	14.77 MBtu/h

---

[2] Since the solvent has a heat of combustion of about 18 400 Btu/lb, it furnishes part of the energy of its own incineration which must be included as a part of the heat input.

OUTPUT

Hot dry steel	0.41 MBtu/h
Stack loss at 1600 °F	13.11 MBtu/h
Other losses and unaccounted	1.25 MBtu/h
Total	14.77 MBtu/h

Inspection of this heat balance shows that the vast majority of the energy input, some 89 percent, is wasted as stack loss. Since this loss cannot be reduced by shutting down the incinerator, or by reducing the large amount of excess air, one must look for ways to utilize this waste heat.

One such technique is shown in figure 5, where a heat exchanger is used to recover part of the stack gas waste heat to preheat the oven exhaust before it enters the incinerator. The new heat balance is:

INPUT

Natural gas to oven	4.79 MBtu/h
Natural gas to incinerator [3]	0 MBtu/h
Solvent vapors	5.33 MBtu/h
Total	10.12 MBtu/h

OUTPUT

Hot dry steel	0.41 MBtu/h
Stack loss at 1050 °F	8.40 MBtu/h
Other losses	1.31 MBtu/h
Total	10.12 MBtu/h

Note that the addition of the heat exchanger and its accompanying duct work has reduced the use of natural gas from 9.44 MBtu/h (fig. 4) to 4.79 MBtu/h (fig. 5). Assuming a natural gas cost of $1.50 per thousand cubic feet, and operation of the system for 4000 hours per year, the annual saving is:

$$\frac{(9.44-4.79)\times 10^{6}\ \text{Btu/h}\times 4000\ \text{h/yr}\times \$1.50/1000\ \text{cf}}{1000\ \text{Btu/cf}}$$

$$=\$28\,000/\text{yr}.$$

Although the heat exchanger has reduced the amount of purchased fuel considerably, there is still a large amount of waste heat in the exhaust flue gas. It is possible to use this heat by installing a second heat exchanger and using it to preheat the incoming air to the oven up to 600 °F. This will require some modifications perhaps to the air distribution system within the oven, but it will do away completely with the need to fire natural gas to the oven except during warm-up or when operating at very low product throughput. At normal production rates, all the heat is furnished by burning the solvent vapors in the incinerator.

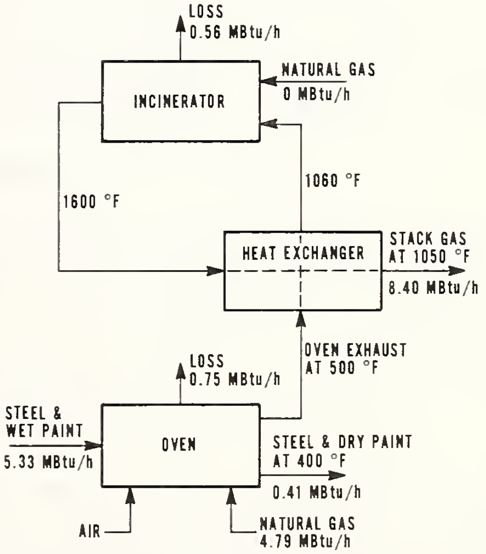

FIGURE 5. *Paint drying oven, fume incinerator, and heat exchanger.*

Another method of conserving energy when incinerating hydrocarbon fumes is to use a catalytic incinerator, similar in principle to the catalytic converters on the exhaust system of modern automobiles. Such a catalytic incinerator can save energy because fume combustion is carried out at much lower temperatures than the normal 1600 °F. Statements by manufacturers mention temperatures as low as 400 °F for combustion of hydrocarbon vapors in excess air. Figure 6 shows a possible use of such a catalytic incinerator with a paint drying oven [3]. The heat balance for figure 6 is:

INPUT

Natural gas	0 MBtu/h
Solvent vapor	5.33 MBtu/h
Total	5.33 MBtu/h

---

[3] Preheating the solvent laden air to the incinerator has eliminated the fuel requirement of the incinerator except that a very small amount of fuel may be needed as a "pilot light" to assure that the gas stream ignites in the incinerator.

OUTPUT

Hot dry steel	0.41 MBtu/h
Evaporation of solvent	0.06 MBtu/h
Stack loss at 500 °F	3.61 MBtu/h
Other losses	1.25 MBtu/h
Total	5.33 MBtu/h

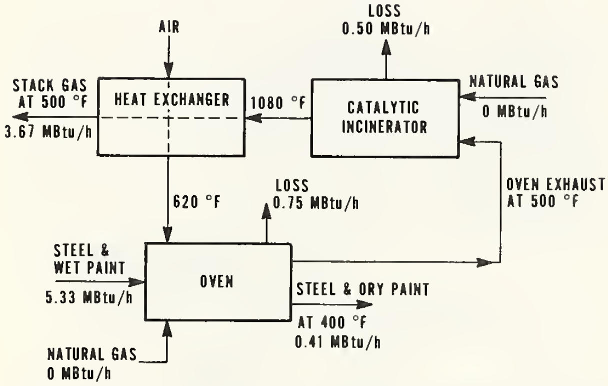

Figure 6. *Paint drying oven, catalytic incinerator, and heat exchanger.*

The heat balance indicates that no heat from natural gas is needed when operating at a normal load. The gas burners indicated on figure 6 will be necessary only during start-up, or when not enough product is being dried to furnish solvent vapor to heat the system.

It should be noted that some catalysts become "poisoned' and cease to work properly if the vapors contain sulfur compounds or heavy metals such as lead. This point should be checked with equipment manufacturers.

A third possible method of energy conservation in paint drying is the use of a patented incinerator which can produce an exhaust stream that is almost free of oxygen; 2 percent is reported. If this gas is used in the oven for heating the product, one can permit the concentration of solvent vapors to reach a much higher level without danger of creating an explosive atmosphere. This means that the volume of gases to be circulated can be cut to about one-half, and that energy can also be saved in the electrical power needed to operate the fans and blowers [4].

The purchased cost of fuel for the three systems is summarized in table 2.

Table 2. *Fuel costs of paint drying systems*

System	Annual fuel cost [a]	Efficiency [b]
	Dollars	Percent
Conventional dryer	56 600	3.2
Heat exchanger added	28 700	4.6
With catalytic incinerator	[c]0	8.8

[a] Cost of natural gas is assumed to be $1.50 per 1000 cubic feet. Operating time is assumed to be 4000 hours per year.

[b] (Energy needed for the product) × (100) divided by the total energy including that in the paint solvent.

[c] Natural gas fuel is needed only during the start-up period or when operating at a low production rate.

If the solvent dried from a paint film is valuable in itself, for reasons other than its fuel value, one should consider recovering it with an activated carbon tower instead of incinerating it. This will not, in general, constitute a saving of energy, but may well be a financial gain. Some newer systems use vacuum to pull the absorbed solvent from the activated carbon, and are reported to use less energy than the older heating technique in recovery of the valuable solvent.

Drying ovens or kilns in general do not lend themselves to rule-of-thumb advice as to the best methods of energy conservation. Each seems to have its own special features, and needs an individual heat balance in order to understand how best to conserve energy. Ovens and kilns almost inevitably, however, have large quantities of waste heat available. If this waste can be utilized for space heating, low pressure steam, hot water, etc., one can improve on the rather low efficiencies listed in the tabulations above. Even with the catalytic incinerator system of figure 6, the stack gas still leaves at 500 °F, and is "wasting" 3.67 MBtu/h.

2.4. A Case Study of Energy Conservation

This section summarizes an actual case study of a slot forging furnace in which energy usage was reduced by following principles discussed in sections 2.2 and 2.3 above. For a complete discussion of this case study, see reference [5].

The outside dimensions of the furnace were 11.5 ft × 5 ft × 6.5 ft, with a slot opening 10 ft long × 6 in high. The furnace heated 2500 lb of steel per hour to 2450 °F, burned 42 gal of No. 2 oil per hour, and exhausted stack gas at 2650 °F. The outside temperature of the furnace walls was 400 °F; the roof, 700 °F. These outside temperatures indicated rather inadequate furnace insulation and posed a safety hazard as well.

The goal of the study was to test a ceramic recuperator (heat exchanger) designed to recover flue gas heat and to preheat the combustion air to 1200 to 1500 °F. The first step, therefore, was to install new burners designed to handle air at these high temperatures. The new burners also recirculated some of the furnace atmosphere thus increasing turbulence and increasing the rate of heat transfer. This new burner installation saved 3.2 gal/h in oil usage.

The second step was to reduce the open slot area 50 percent by lowering the height from 6 in to 3 in. This simple change saved an additional 6.5 gal/h.

The third step was to achieve close control of the air/fuel ratio, i.e., to minimize the amount of excess air. At the same time, the furnace pressure was adjusted to prevent cold air infiltration. These operational adjustments saved 4.5 gal/h of fuel.

A fourth step was to install the recuperator, which was successful in recovering about 50 percent of the stack gas heat and preheating the combustion air to 1300 °F. The rate of fuel flow was reduced 10.5 gal/h by this step.

A proposed fifth step was to install improved insulation that was designed to reduce the outside furnace wall and roof temperatures to 250 °F and to save an additional 3.5 gal/h of fuel oil. This final step was not physically accomplished during the case study.

Table 3 summarizes the step-by-step savings achieved during this lengthy experiment.

Table 3. *Steps to reduce fuel usage in a slot forging furnace*

Step	Fuel consumption	Saving for this step	Saving from original
	gal/h	Percent	Percent
Original system	42.0	. .	. .
(1) New burners	38.8	7.6	7.6
(2) Reduced slot area	32.3	16.8	23.1
(3) Better operations	27.8	13.9	33.8
(4) Preheated air	17.3	37.8	58.8
(5) Insulation (proposed)	13.8	20.2	67.1

With the exception of the fifth step, all of the savings listed above are the result of actual fuel flow measurements taken on equipment operating under production conditions. Unfortunately, data are not available to calculate heat balances at each step and to compare forecasted savings with those actually obtained. The measurements do demonstrate, however, that savings comparable to those estimated by heat balances are obtainable in practice.

3. Summary of Energy Conservation Opportunities (ECO's)

This section summarizes the different categories of Energy Conservation Opportunities which exist on direct fired manufacturing equipment. It is not exhaustive in the sense of covering every detailed conservation possibility; it does attempt to cover the important areas.

3.1. Control Excess Air

As illustrated in figure 2 and discussed in [6] and [7], the use of a greater amount of combustion air than is necessary can constitute a major energy waste. The use of insufficient air is just as wasteful, but probably less common due to recent emphasis on air pollution problems, particularly visible smoke formation.

There is no accurate data on just how much excess air is used in the "average" furnace, or how much energy is wasted annually due to poor control of air/fuel ratios. Competent writers on the subject agree, however, that it is a subject of first importance in energy conservation [6, 7, and 8].

This handbook, in section 2.2, illustrates how the energy savings due to the adjustment of excess air can be estimated. It must be recognized, however, that all such estimating methods have limits to their accuracy. For example, reducing the amount of combustion air with no change in the rate at which fuel is fired will result in a higher flame temperature and hence a more rapid heating of the work and an energy saving shorter cycle. It will also, however, increase the flue gas temperature and therefore affect the stack loss. If, in addition to reducing air flow, the fuel flow is also reduced to maintain the same stack temperature, one will have a decreased gas velocity and less turbulence in the furnace, and an increased residence time of the hot gases within the combustion chamber. The exact effect of these latter two changes on heat transfer to the work and to the furnace walls is not always evident or readily estimated. Therefore, in order to find out accurately the savings achieved, one must make a new heat balance.

In spite of these complexities, the control of excess air is probably the single most important item in energy conservation in furnaces. The determination of excess air by means of a flue gas analysis is essential, in any event, to the calculation of stack losses and the setting up of a heat balance.

3.2. Recover Waste Heat

An industrial furnace, kiln, or oven almost inevitably exhausts gas at some temperature above the ambient, and hence this gas contains useful energy which can be recovered. The uses to which recovered energy can be put are numerous. If the gas is at a high temperature, say 1500 °F or higher, it can be used to generate steam to perform mechanical work or to generate electricity. Lower temperature gas streams can be useful and save cost in such applications as drying and preheating incoming products, in heating water, or in space heating. If the stream is only a few degrees above the ambient temperature it may still contain much energy, however it may well be impossible to recover it economically.

If recoverable energy is not available on a regularly scheduled or continuous basis, it is usually best to try to return it to the same system that produced it. An example is the use of stack gas heat from an intermittently operated furnace to preheat the combustion air for the same furnace. This application is discussed in detail in reference [5]. In this application waste heat still exists at a reasonably high temperature and could be useful for space heating or for drying even if it had to be supplemented during furnace shutdown by an auxiliary heater.

The "Waste Heat Management Guidebook" [9] contains much information and several case studies on energy recovery. Some of the different types of equipment used for heat recovery are illustrated in figures 7 through 10, which are taken from this guidebook. See also [1] (EPIC) for additional case studies.

3.3. Insulation

Furnace insulation that is inadequate or in poor condition can waste large amounts of energy, and usually in a form that is not readily recoverable. For example, the case study of section 2.4 describes an actual furnace where 20 percent of the fuel energy was still being lost through the insulation after the other obvious steps to conserve energy had been taken.

The best method of detecting large losses through the insulation is to perform a heat balance as described in section 2. One may get an indication of the importance of the losses by measuring the temperature of the outside furnace walls and roof. A temperature of 175 to 250 °F indicates that the losses are reasonable. A temperature of 500 °F or higher means that the losses are probably quite large. An estimate of the energy loss per square foot per hour as a function of outside wall temperature is shown in figure 11.

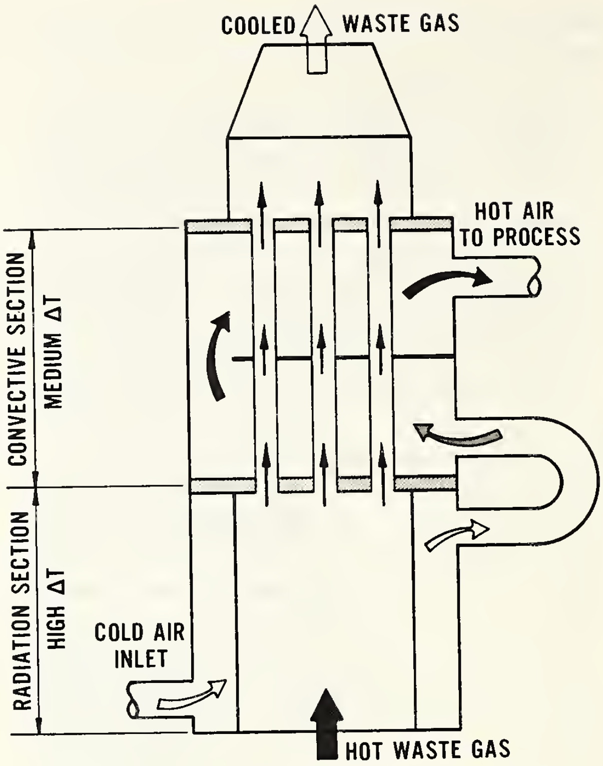

Figure 7. *Diagram of combined radiation- and convective-type recuperator.*

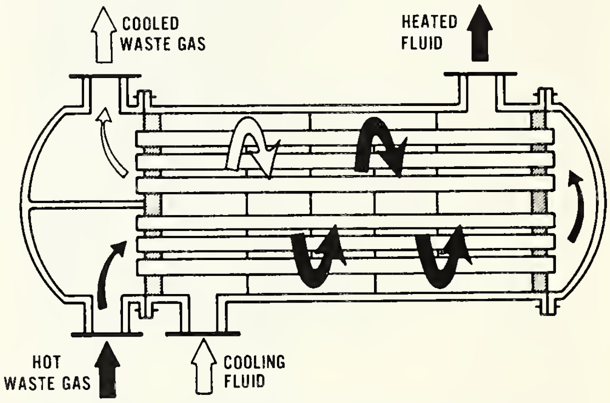

Figure 8. *Diagram of convective-type recuperator.*

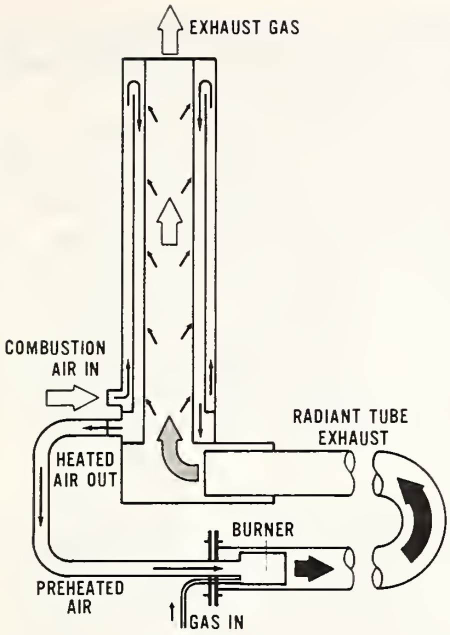

FIGURE 9. *Diagram of a small radiation-type recuperator fitted to a radiant tube burner.*

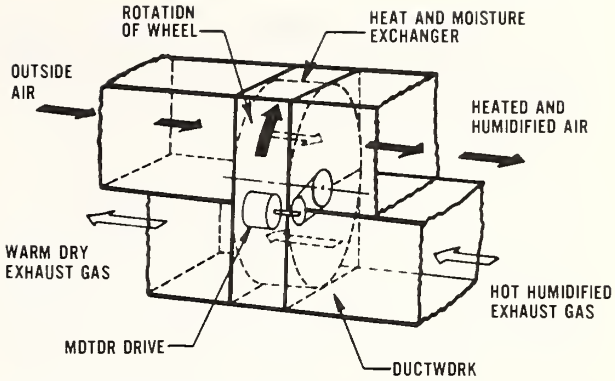
ROTATION OF WHEEL
HEAT AND MOISTURE EXCHANGER
OUTSIDE AIR
HEATED AND HUMIDIFIED AIR
WARM DRY EXHAUST GAS
HOT HUMIDIFIED EXHAUST GAS
MOTOR DRIVE
DUCTWORK

FIGURE 10. *Heat and moisture recovery using a heat wheel type regenerator.*

For a large installation, an infrared thermographic survey as described in [9] will accurately indicate the temperature of large complex areas. It will also serve to identify hot spots, even quite small ones, caused by locally damaged insulation.

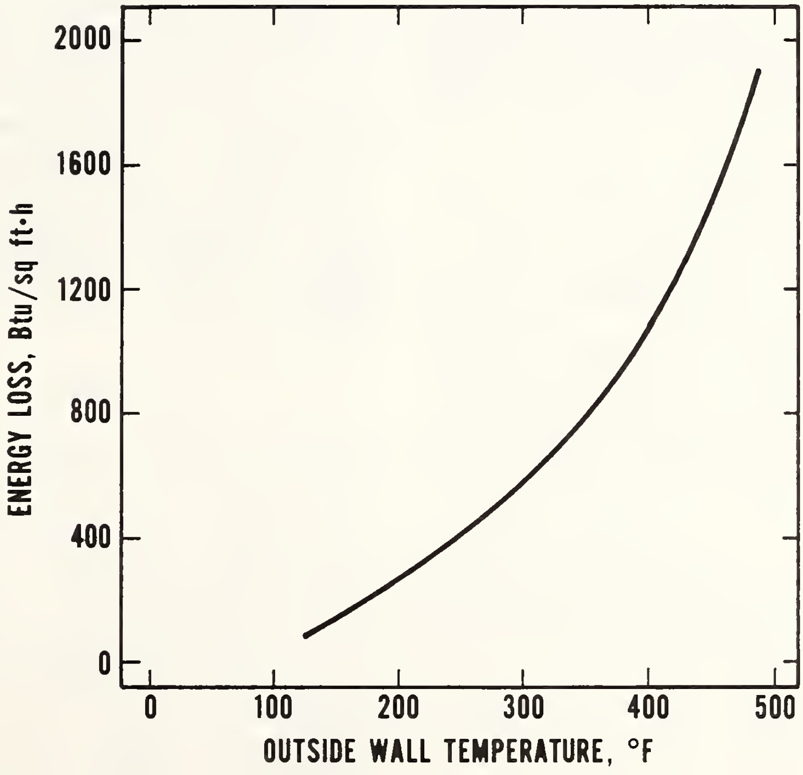

FIGURE 11. *Energy loss from furnace walls versus outside wall temperature.*

When installing new insulation or when retrofitting existing equipment, one should consider using ceramic fiber blankets instead of conventional fire brick. Ceramic fiber offers distinct advantages:

○ It has only one-third to one-half the heat conductivity of fire brick and may be installed in correspondingly thinner layers for a given heat loss.

○ It has a heat storage capacity of approximately one-tenth that of an equivalent layer of insulating brick. This feature saves both energy and time in start-up, or in reheating during a batch cycling operation [1, EPIC Supplement 1, ECO 3.7.2].

○ It is immune to failures by spalling or cracking due to rapid heating and cooling.

○ Its light weight makes it possible to install it without major rebuilding of a furnace.

It likewise has some disadvantages:

○ Since it is very poor in physical strength, it cannot be installed on furnace floors or in other areas where it would be subjected to mechanical abrasion.

○ Since its insulating properties depend on its high porosity, its use should be questioned in any service where the pores might be plugged up by deposits from fumes or by particulate matter.

○ It is intended for installation on the hot side of furnace walls or roofs. A blanket of fiber on the cold side of an existing furnace wall may cause some of the interior layers of brick to heat beyond their useful service temperature.

For additional information on ceramic fiber, see references [10] and [11].

3.4. Openings and Leaks

Open ports or leaks in a furnace system waste energy by radiation losses, by losses due to gas flow through the openings, or by a combination of the two.

Radiation is a line of sight phenomenon. If we can see the hot interior of the furnace, heat is being lost by radiation. The amount of heat loss is linearly proportional to the area of the opening and is approximately proportional to the fourth power of the absolute temperature.[4] The rate of energy loss is shown in figure 12, based on data from reference [12].

As an example, a slot opening 6 inches high by 8 feet long in a 2200 °F forging furnace will lose heat by radiation at a rate of $79\,000 \times (0.5 \times 8) = 316\,000$ Btu/h. This is in addition to any loss resulting from gases flowing through the opening.

Outward gas flow through a port or leak is generally not a major source of energy loss. If the leak is merely completely burned hot gas from the furnace, it represents a small amount of exhaust gas which otherwise would have been wasted up the stack. If the outward leak results in long flames outside the furnace, it represents incomplete combustion, probably due to a too-rich fuel-air mixture. Such flames represent an energy waste and should be eliminated by proper adjustment of the amount of combustion air.

The infiltration of cold air into the furnace represents a serious energy loss. Every pound of excess cold air leaking into a 2200 °F furnace wastes 510 Btu. Such infiltration commonly occurs because in the absence of a well adjusted flue damper there tends to be a slight vacuum near the bottom of the combustion chamber. Due to the "chimney effect," the pressure will be lowest at the furnace floor and will gradually rise to the local barometric pressure at the point where the stack exhausts to the atmosphere. The pressure difference, hence the volume of the air infiltrated and the amount of energy lost, depends on the furnace temperature, the height of the flue gas exit above the furnace floor, and the size of the opening through which cold air is entering. Table 4, which illustrates the relationship among these variables, is calculated from data given in reference [13].

Thus a slot opening 8 feet long by 6 inches high in a 2000 °F forging furnace, with the stack exhaust located 16 feet above the furnace floor, would have the following heat loss due to the air infiltration:

$$(18\,500 \text{ Btu/h}\cdot\text{sq in}) \times (8 \times 0.5) \text{ sq ft} \times (144 \text{ sq in/sq ft}) = 10\,600\,000 \text{ Btu/h}.$$

This is equivalent to 76 gal of No. 2 fuel oil wasted per hour. To prevent such an excessive loss one must install a damper or other constriction in the exhaust stack in order to increase the pressure in the combustion chamber to atmospheric or slightly higher. A frequent recommendation, even with openings or leaks much smaller than that described above, is to install an automatically controlled damper to maintain a positive pressure of 0.01 to 0.05 inches of water. Thus if leaks do occur, they will be small outward leaks and will waste far less energy than will cold air infiltration.

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[4] The temperature above "absolute zero", called absolute temperature, is given on the Rankine scale (in °R) by adding 459.67 to the Fahrenheit temperature.

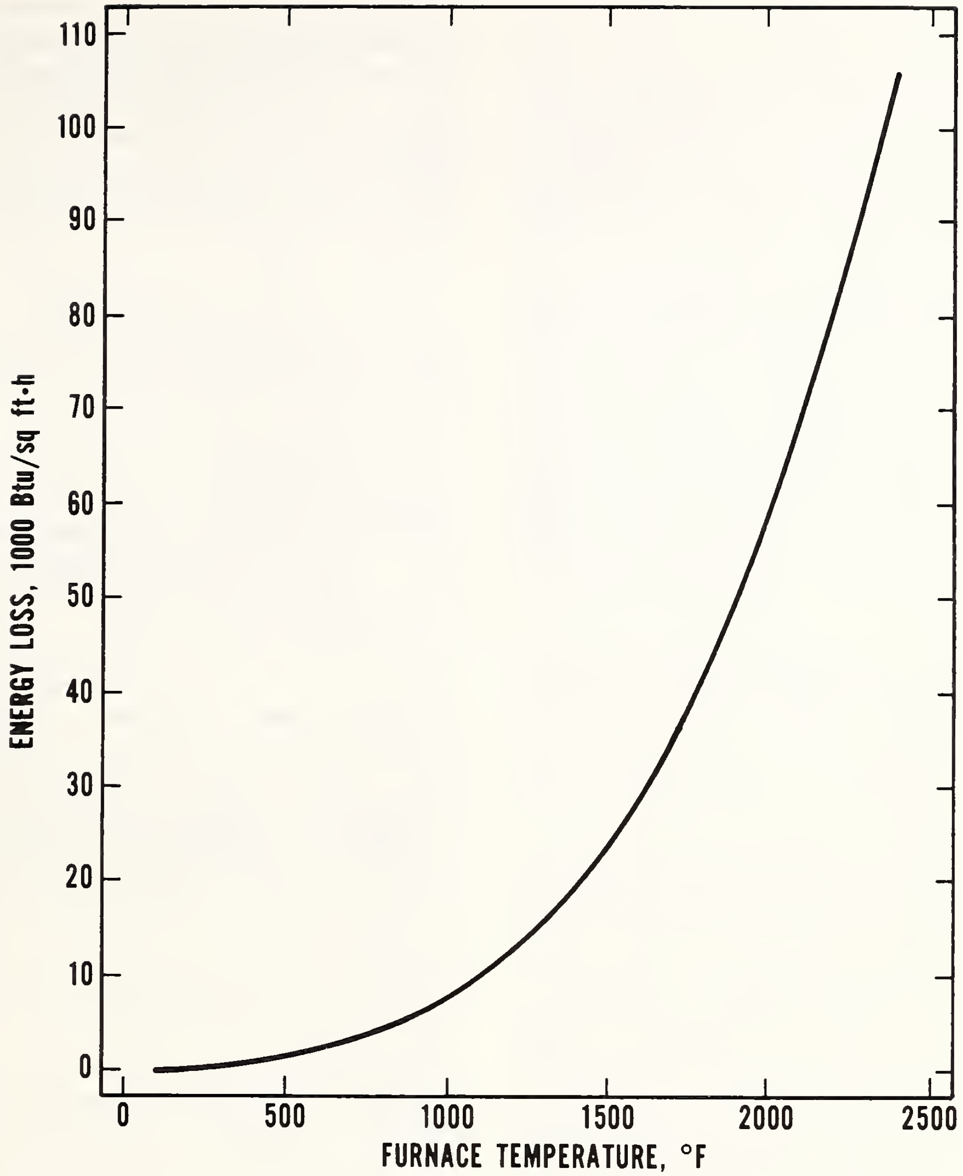

Figure 12. *Energy loss by radiation through openings versus furnace temperature.*

Table 4. *Heat loss due to chimney effect*

Furnace Temperature	Heat loss per hour per sq ft of opening, for furnace floor to stack exhaust height of:					
	6 ft	8 ft	10 ft	12 ft	16 ft	20 ft
°F	Btu	Btu	Btu	Btu	Btu	Btu
800	3 600	4 000	4 800	5 200	6 100	6 900
1 200	5 500	6 900	7 500	8 100	9 800	11 000
1 600	8 200	10 200	11 200	12 700	15 200	17 500
2 000	10 510	13 200	14 700	16 500	18 500	21 300
2 400	13 500	16 200	18 100	20 500	23 200	25 900

3.5. Shut Down Idle Equipment

When heating equipment is out of service, either due to scheduled shutdowns or to interruptions in production, energy can almost always be saved by allowing the equipment to cool down and reheating it later. If the shutdown time is short, it may be best to permit the equipment to cool to some intermediate temperature, to idle at this reduced temperature for a period, and then reheat to the operating temperature.

Unfortunately there seems to be no good general law or rule-of-thumb as to when to shut down, when to idle at lowered temperature, and when to hold at operating temperature. The best decision depends not only on the projected down time, but most importantly on the characteristics of the specific piece of equipment under consideration. To reach a decision which will save the most energy, one needs several bits of information:

○ The time required for the equipment, with burners off, to cool to room temperature and several intermediate temperatures.

○ The rate of fuel flow required to idle at operating temperature and at each of the intermediate temperatures.

○ The time required to reheat from room temperature and from each of the intermediate temperatures.

○ The total fuel required to reheat from each of the above temperatures.

○ The maximum rate of temperature change that will not result in equipment damage.

With this information and a projected down time schedule, the cycle which uses the least fuel is easily determined. This process is further discussed and illustrated in EPIC [1, ECO 3.9.1 and 3.9.2].

It is recognized that in some cases the desired shutdown and reheat cycle may incur some additional labor costs; in others, product or equipment may be damaged by excessive rates of heating or cooling. These costs must, of course, be balanced against the savings in the cost of energy.

3.6. Schedule Furnace Output for Efficient Operation

It is better to operate heating equipment at the most efficient operating load rather than at some lower production rate. It is simple to translate this conventional wisdom to actual fuel usage and costs.

As an example, consider a continuous brazing furnace fired at the rate of 5×10^6 Btu per hour, with a full load capacity of 100 units of product per hour. A heat balance shows that 1×10^6 Btu actually heats the product (10 000 Btu/unit), while the other 4×10^6 Btu goes to stack and other losses. This is a reasonably high energy efficiency for a heat treating operation [14]. If the required production rate is reduced to one-third of the furnace capacity, two general alternatives apply:

(1) The furnace can be operated at 100 units per hour, but only operated every third day or third week. The fuel usage will be 5×10^6 Btu/h or 50 000 Btu per unit of product, disregarding the energy required to reheat the furnace to working temperature.

(2) The furnace can be operated every day with product fed at only 33 units per hour. Under these conditions, the furnace will still waste energy at the rate of 4×10^6 Btu/h and will deliver 330 000 Btu/h to the product. Total fuel usage will be 4 330 000 Btu/h or 131 000 Btu per unit.

The second alternative is probably more convenient to schedule in that it minimizes the problems of material handling, of storage space for a larger work-in-process inventory, and of poor worker morale that sometimes (not always!) results from frequent changes in job assignments. It also increases by 81 000 Btu the energy used per unit of product. With oil at 35¢ per gallon, this represents a cost increase of 20¢ per unit.

Alternative number one, in spite of its scheduling inconvenience, is very attractive.

In some cases one may desire to increase the throughput of an existing furnace. If in the previous example one wished to increase the production rate from 100 to 120 units per hour, it could conceivably be accomplished by speeding up the conveyor mechanism by 20 percent. Since this would reduce the dwell time of the product in the furnace, it might be necessary to increase the heat transfer rate by raising the temperature of the furnace atmosphere, thus increasing the fuel consumption per hour. The higher temperature in the furnace would result in increases in stack loss and in the loss through furnace walls and roof. The increased volume of hot gas flowing would cause greater turbulence, which would increase both the heat transfer to the product and the loss through the walls.

The result of all of these conflicting changes is very difficult to estimate; it might be that the scheme is possible, but only at a sacrifice in efficiency, i.e., an increase in fuel used per unit of product. If the conveyor already has a variable speed drive, it might be possible to try the proposal and generate a new heat balance. If not, a discussion with the furnace manufacturer or a competent consultant is suggested before expensive and irreversible changes are made. A discussion of factors controlling efficiency of furnaces including the effect of throughput loading is given by Essenhigh and Tsai [15] [16].

3.7. Minimize Energy Loss During Cycling

When a batch furnace is opened to remove one load and put in another, it is obvious that large amounts of energy are lost by radiation and cold air infiltration as discussed in section 3.4. The loss can be measured by a rather simple experiment:

(1) Open the hot furnace and remove a batch of product as usual.

(2) Reload any jigs or fixtures that are normally used but do not load any product into the furnace.

(During the steps above, the furnace should be open for the length of time that is normal in production.)

(3) Close the furnace, and reheat to operating temperature.

The amount of fuel used during these steps is a direct measure of the loss due to cycling.

The major source of the energy lost is the stored heat or sensible heat in the hot furnace walls, floors, and roof. The loss mechanisms are both radiation and cold air infiltration through the open door(s), as discussed in section 6.4. The normal heat loss by conduction through the furnace walls is usually small when compared to this "open door" loss. Another (usually less important) source of energy lost is the sensible heat of any jigs, fixtures, or carriers which must be heated and cooled during each cycle. These facts point to several techniques of conserving energy:

○ Since the heat flow through open doors is a function of time, energy is saved by keeping the open-door time as short as possible. If, for example, one must wait 10 minutes for arrival of the next batch of product to be treated, shut the door during the waiting period.

○ Supporting jigs and fixtures should be designed for minimum heat capacity. In general, this means designing to minimum mass. Note that in terms of heat capacity per pound, most metals store only half as much heat as do ceramics [12] [17].

○ The most important method of saving energy in a furnace which must be cycled is to use an insulating material which has a very low heat capacity per unit volume, such as ceramic fiber. The following analysis is based on data furnished by an insulation manufacturer:

A wall of insulating fire brick, designed for furnace temperature of 2000 °F and a cold face at 200 °F, would be about 12 inches thick and would store 12 600 Btu/sq ft of sensible heat. In a furnace with inside dimensions of 8 ft × 6 ft × 5 ft, this amounts to a total storage of 2 970 000 Btu. If the furnace cooled to 1700 °F during a batch change, the storage would be reduced to 2 510 000 Btu and the energy loss would be 460 000 Btu.

Ceramic fiber insulation, on the other hand, would be only 4.7 inches thick and would store only 680 Btu/sq ft. The total stored heat would be 733 000 Btu, most of it in the brick floor, and the loss in cooling from 2000 to 1700 °F would be only 114 000 Btu. Assuming a stack loss of 45 percent during the reheat period, the fuel saving due to ceramic fiber insulation is:

$$\frac{(460\,000 - 114\,000)\ \text{Btu}}{(1-0.45) \times 140\,000\ \text{Btu/gal}} = 4.5\ \text{gal of fuel oil.}$$

If, instead, the temperature dropped to 1500 °F during cycling, the saving would be 7.2 gal of oil.

For heating up from room temperature, the firebrick insulation would require 38.5 gal of oil; the ceramic fiber design only 9.5 gal.

3.8. Miscellaneous Energy Conservation Opportunities

There are many practices and procedures that waste energy but go unnoticed because "we have always done it this way." This listing cannot pretend to be exhaustive, but covers some of the more important points. Note that these practices are apt to be those that were started when the cost of energy was rather unimportant:

○ Over-specification by the parts designer is sometimes due to an early desire for a large factor of safety, to a reluctance to change something that is working, or to a lack of appreciation of the present cost of energy and its probable future increase. Examples include such things as a carburized case specification of 0.040 in when 0.020 in is adequate, or a drying and baking schedule for a painted part of one hour when 20 minutes is long enough. Design engineers will usually welcome cost saving suggestions, particularly if the credit is shared.

○ Production people are guilty of an energy waste when they extend an annealing cycle two hours longer than is necessary or when they start heating up a cold furnace earlier than need be because "it is more convenient." Education and an energy conscious approach are needed.

○ Protective gas atmospheres which are allowed to flow at a greater rate than is essential are wasting energy, both in the mass of gas which must be heated in the furnace and in the fuel value of the protective gas used.

○ Massive jigs, carriers, or fixtures which must be heated and cooled with each batch or with each trip through a continuous furnace constitute a built-in energy waste. Such jigs should be as low in weight as possible. In some cases they can be completely eliminated.

○ Water cooled rails, supports, door parts, etc., waste energy with every gallon of warm water that is sent to the drain. They can often be replaced with parts made of heat resistant alloys or ceramics, or the heat in the water may be recovered.

○ Scaling problems have sometimes been controlled by using expensive alloys when the same result might have been achieved by adjusting the excess air to keep the furnace atmosphere down to 1 or 2 percent oxygen. The latter course saves energy both in the heat treating furnace and in the alloy preparation.

3.9. Continuous Efficiency Monitoring

The most efficient of furnaces can drift from its optimum adjustments unless it is monitored on a regular basis.

The most important monitoring instrument is a fuel usage meter. Preferably, one should be installed on each major piece of fuel-using equipment and read at the beginning and end of each shift or, at least, weekly. A graph or a tabulation of fuel consumption per unit of production will show changes in equipment or in production practices which affect energy efficiency adversely. Just as important, such monitoring will indicate the efficacy of an energy conservation project.

Fuel monitoring is the most important measurement for energy efficiency, but it has its limitations. It can detect some of the causes of possible energy waste, particularly those that have to do with schedule changes such as excessive idling, changes in batch size, changes in product design, etc. In the case of other possible causes for energy waste, such as a change in the amount of combustion air, fuel monitoring alone will disclose a change but will give no clues as to the cause. For this reason, some additional monitoring is desirable.

As discussed in other sections of this handbook, a complete flue gas analysis is a very useful tool for checking furnace efficiency. Such an analysis is suggested at regular intervals. Possible schedules might be set up for checking monthly, quarterly, or after 500 to 1000 hours of operation.

For a major user of energy, one should consider the installation of an electronic instrument for the continuous indication and/or recording of oxygen content in the flue gas. Such an instrument will indicate very rapidly any change in the amount of combustion air, a change in air infiltration, or even problems with a new batch of fuel oil. The cost of such an installation may be difficult to justify in some cases, but the speed with which it can indicate trouble can save both fuel and production material. Note also that if it shows a rapidly decreasing amount of oxygen in the flue gas, it can be a warning of possible air pollution problems.

An instrument for measuring flue gas temperature is not often installed, since it can be assumed that this temperature depends directly on the control temperature in the furnace. If, however, a recuperator or other waste heat recovery device is installed, one should measure the temperature at the flue gas outlet from this heat exchanger. A change in this temperature, if not accompanied by a change in furnace temperature, would indicate that the heat exchanger is not operating properly and needs maintenance or repair.

No monitoring instrument can replace the need for a good preventive maintenance program. The reverse is also true; the best of maintenance skills does not do the same job as instrumentation. To hold to a high level of energy management, both maintenance and monitoring are needed.

4. Methods of Calculation

If one is estimating a heat balance for the purposes described in this guide, the calculations are few in number and are not complex. If, on the other hand, an engineer is designing a complex system the job is more complicated, the calculations more numerous, and the results must be more accurate. The methods described here are of the simpler type, and an accuracy of ±5 to 10 percent may be expected.

In estimating a heat balance, there are three different types of heat energy that must be considered: heat of combustion, sensible heat, and process heat.

4.1. Heat of Combustion

Heat of combustion is the energy released when fuel is burned. There are two heating values given for any fuel. The gross (or "higher") heating value is that which would be realized by completely burning the fuel to carbon dioxide and water and condensing all the water produced to liquid at 25 °C to recover heat of vaporization. The net (or "lower") heating value is the gross heating value minus the heat of vaporization of the water in the combustion products.

Both these heating values are in a sense artificial, but they are useful for heat balances and for use in comparing fuels. In calculating heat balances, we have ignored the difference between net and gross values. This introduces a small error, less than 5 percent, but serves to simplify calculations.

Table 5 lists the approximate gross heat of combustion of typical samples of a few common fuels [1]. Additional gross heating values for different grades of fuel oil [1] are given in table 6. In most cases your fuel vendor can furnish you a more accurate figure for the heat of combustion of the fuel you are using. Since oils and coals can vary over a reasonably wide range, it is strongly suggested that you do contact your vendor for an accurate figure.

TABLE 5. *Gross heat of combustion of common fuels*

Fuel	Density		Gross heat of combustion	
	lb/gal	lb/scf [a]	Btu/lb	Btu/scf [a]
Natural gas	..	0.0425	23 500	1000
Fuel oil, #2	7.20	..	19 500	..
Propane	4.22	0.120	21 700	2530
Coal	..	..	14 000	..
Air	..	0.0766	..	..

[a] The standard cubic foot (scf) is determined at 60 °F and sea-level atmospheric pressure. The effect on gas volume due to changes of temperature and pressure is discussed in section 4.6.

TABLE 6. *Gross heat of combustion of fuel oil by grade*

Fuel Oil	Density	Gross heat of combustion
Grade	lb/gal	Btu/lb
#1	6.83	19 780
#2	7.20	19 500
#4	7.58	19 190
#5	7.89	18 930
#6	8.50	18 390

4.2. Sensible Heat

Sensible heat is the energy contained in a material because of its temperature; it can be "sensed." Since it is dependent on temperature, it is convenient to choose a base temperature as a reference, and for this discussion 70 °F has been chosen as the base. This means that a material at 70 °F is considered to have no sensible heat; at higher temperature it does have sensible heat. The amount of sensible heat is expressed by

$$H = m \times C_p \times \Delta t$$

where

H = sensible heat in Btu,
m = mass of the material in pounds,
C_p = specific heat of the material in Btu/lb·°F, and
Δt = temperature of the material in °F minus 70 °F.

Since the Btu is defined as the energy required to raise the temperature of one pound of water one degree Fahrenheit, the specific heat of water is one Btu/lb·°F. The specific heats of some common materials [12] are shown in table 7.

TABLE 7. *Specific heat of some common materials*

Material	Specific heat
	Btu/lb·°F
Air	0.24
Flue gas	0.24
Carbon dioxide	0.20
Nitrogen	0.25
Oxygen	0.22
Water vapor	0.45
Steel	0.12
Aluminum	0.22
Copper	0.095
Glass	0.20
Brick	0.21
Water	1.00

As an example, the heat flow represented by aluminum leaving an oven heated to 450 °F, at the rate of 200 lb/min, is

$$H = 200\ \text{lb/min} \times 0.22\ \text{Btu/lb}\cdot{}^\circ\text{F} \times (450-70)\ {}^\circ\text{F} = 16\,700\ \text{Btu/min}.$$

As a second example, suppose one knows from previous calculations that the heat carried by a stream of flue gas is 5 000 000 Btu/h, that its measured temperature is 550 °F, and one desires to know the mass flow. The original equation, $H=m\times C_p\times\Delta t$, can be rearranged to read

$$m = \frac{H}{C_p\times\Delta t}.$$

Therefore,

$$\text{mass flow} = \frac{5\,000\,000\ \text{Btu/h}}{0.24\ \text{Btu/lb}\cdot{}^\circ\text{F}\times(550-70)\ {}^\circ\text{F}} = 43\,400\ \text{lb/h}.$$

4.3. Process Heat

The third type of heat that it is necessary to consider in some heat balances can be called "process heat." For the purpose of this guide, we will define it as the heat needed to change the physical or chemical state of a product without changing its temperature. For example, about 1054 Btu is needed to change a pound of water at 70 °F into vapor at 70 °F, and even more energy is then needed to heat the vapor to a high temperature as in a steam boiler. The 1054 Btu is the heat of vaporization of water.

Another example is the heat necessary to turn a crystalline solid into a liquid; the heat of fusion. This can vary from 200 Btu/lb for salt, to 10 Btu/lb for lead, to essentially zero for materials like plastics that do not have a definite melting point [17].

Many chemical reactions involve a third type of process heat; the heat of reaction. The heat of combustion discussed above is, of course, a special and very important case of a reaction which releases large amounts of heat. Some reactions, however, will absorb heat. The burning of limestone to quicklime, for example, requires 750 Btu per pound of stone fired in addition to the heat needed to get the material up to the reaction temperature. Such reactions can be important in heat balance calculations in chemical manufacture, in smelting ores, and in making cement.

For the manufacturing areas considered in this guide, the most important type of process heat is the heat of vaporization of any fluid to be driven off by a drying process. Table 8 shows this energy for a few representative solvents [17].

TABLE 8. *Heat of vaporization of some solvents*

Solvent	Heat of vaporization
	Btu/lb
Water	1054
Acetone	220
Benzene	170
Ethyl alcohol	370
Propyl alcohol	290
Trichloroethylene (TCE)	100
Ethyl acetate	180
Gasoline	110
Turpentine	125

4.4. Calculations for a Heat Balance (Paint Drying Oven)

Utilizing the concepts above, the heat balance for the paint dryer shown previously in figure 4 and, with more detail, in figure 13 was calculated as follows.

First, it was assumed that these data and measurements were available:

Mass of steel processed [5]	10 000 lb/h
Mass of paint solids used [5]	310 lb/h
Mass of paint solvent [5]	290 lb/h
Solvent, heat of combustion	18 400 Btu/lb
Solvent, heat of vaporization	185 Btu/lb
Gas to oven (4800 scfh) [5]	204 lb/h
Gas to incinerator (4670 scfh) [5]	198 lb/h
Air input (455 000 scfh) [5]	34 853 lb/h
Temperature of output steel [5]	400 °F
Temperature of stack gas [5]	1600 °F

Using these data, a tabulation of all of the material and energy inputs to the system was made:

	INPUT	
Steel	10 000 lb/h	0 Btu/h[6]
Paint solids	310 lb/h	0 Btu/h[6]
Paint solvent	290 lb/h	5 330 000 Btu/h[7]
Gas (204+198) lb/h	402 lb/h	9 447 000 Btu/h[8]
Air	34 853 lb/h	0 Btu/h[6]
TOTAL	45 855 lb/h	14 777 000 Btu/h.

---

[5] See section 5 for methods of measurement.

[6] Since these are at 70 °F, they contain no sensible heat.

[7] 290 lb/h × 18 400 Btu/lb = 5 330 000 Btu/h.

[8] 402 lb/h × 23 500 Btu/lb = 9 447 000 Btu/h.

The next step is to tabulate all of the mass and energy outputs of the system. In order to do this, one must calculate the mass and energy of the hot stack gas. The mass is simply the sum of the masses of input air, the natural gas, and paint solvent:

Air	34 853 lb/h
Gas	402 lb/h
Solvent	290 lb/h
TOTAL	35 545 lb/h.

At 1600 °F, the sensible heat in the stack gas is:

$$H = 35\,545 \text{ lb/h} \times 0.24 \text{ Btu/lb}\cdot{}^\circ\text{F} \times (1600-70)\ {}^\circ\text{F} = 13\,052\,000 \text{ Btu/h}.$$

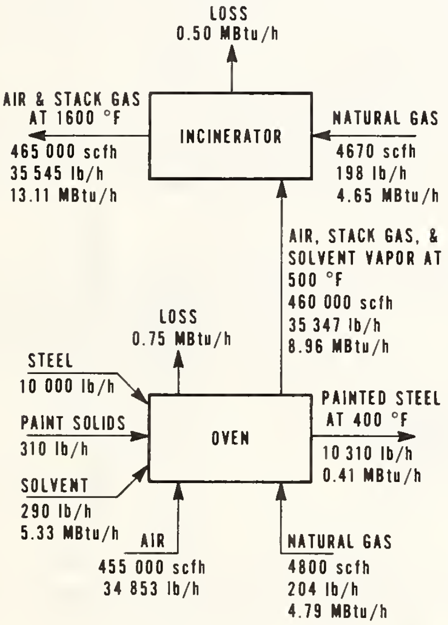

Figure 13. *Heat balance for a paint drying oven and fume incinerator.*

To this must be added the process heat (the energy used to evaporate the solvent) using the heat of vaporization, 185 Btu/lb:

$$H = 290 \text{ lb/h} \times 185 \text{ Btu/lb} = 54\,000 \text{ Btu/h}.$$

The total stack loss is the sum of the sensible heat and the process heat, or 13 106 000 Btu/h.

The energy leaving the system with the painted steel is:

$$H = 10\,310 \text{ lb/h} \times 0.12 \text{ Btu/lb}\cdot{}^\circ\text{F} \times (400-70)\ {}^\circ\text{F} = 408\,000 \text{ Btu/h}.$$

The last two calculations account for (13 106 000 + 408 000) Btu/h or 13 514 000 Btu/h. Subtracting this from 14 777 000 Btu/h, the total input, leaves some 1 263 000 Btu/h which is not accounted for. This energy is the amount that was lost by radiation and convection from the surfaces of the oven, the incinerator, and the duct work. It can also, of course, be partially due to errors in measurement. In the output tabulation it is listed as "other losses":

	OUTPUT	
Painted steel	10 310 lb/h	408 000 Btu/h
Stack gas	35 545 lb/h	13 106 000 Btu/h
Other losses	— lb/h	1 263 000 Btu/h
TOTAL	45 855 lb/h	14 777 000 Btu/h

The very large stack loss suggests that the first order of priority in energy conservation is to recover some of this waste heat. A possible method of doing this was shown in figure 5, where heat from the stack is used to preheat the oven exhaust before it enters the incinerator. To evaluate this possibility, one needs an estimated heat balance on the proposed system in order to find out how much fuel might be saved.

Before proceeding with a complete heat balance, however, a quick check on feasibility can be done. It is obvious from inspection of figure 5 that any fuel saving achieved will be in the amount of gas fed to the incinerator. This gas, in the original system, is furnishing 4.65 MBtu/h (million Btu per hour). Can this much energy be recovered by the proposed heat exchanger?

The purpose of the heat exchanger is to heat the 500 °F oven exhaust up to a temperature which will start the ignition of the solvent vapors. In so doing, the stream of 1600 °F flue gas will be cooled to some extent. It can not, however, be cooled below the 500 °F of the oven exhaust; for the heat exchanger to work properly the cooled flue gas must exit at a temperature above 500 °F. The question now becomes, what is the estimated temperature of the flue gas after 4.65 MBtu/h has been recovered by the heat exchanger?

From the previous calculations, it is known that the 1600 °F flue gas from the incinerator carries 13.05 MBtu/h in sensible heat. If 4.65 MBtu is taken from it, the exit gas will carry 8.40 MBtu/h, and its temperature can be estimated by rearranging the sensible heat equation to read:

$$\Delta t = \frac{H}{m \times C_p}$$

$$= \frac{8.40 \times 10^6 \text{ Btu/h}}{35\,545 \text{ lb/h} \times 0.24 \text{ Btu/lb}\cdot{}^\circ\text{F}}$$

$$= 980\ {}^\circ\text{F}$$

$$t = (980+70)\ {}^\circ\text{F} = 1050\ {}^\circ\text{F}.$$

Since the temperature of the stream from the oven to be heated has been measured at 500 °F, it seems safe to assume that the heat exchanger will work as planned, and that all of the gas now fed to the incinerator can be saved.

Having ascertained that no gas will be needed at the incinerator, and having estimated the new stack loss, 8.40 MBtu/h, one has all the information needed to construct a new heat balance on the system. Assuming a gas cost of $1.50 per 1000 cf and operation for 4000 hours per year, the annual saving can be estimated as 4670 cfh × 4000 h/yr × $1.50/1000 cf = $28 000 per year.

Savings estimates of this type must be approached with some caution. In the present case, for example, some gas must be burned in the incinerator when starting up a cold system in order to get the incinerator up to the required 1600 °F. Perhaps more importantly, if the system is run at a lowered production rate while the air flow through the oven is maintained at full rate, there will be a need to burn some gas continuously to keep the incinerator hot. Such practices will definitely reduce the estimated saving. An equipment designer or a consultant can assist in evaluating the effects of such interruptions and lowered production rates.

4.5. Calculations from Flue Gas Analysis

In direct fired systems which do not require large quantities of excess air it is much more convenient and accurate to start calculations from a flue gas analysis rather than from measurements of air flow in a large duct or stack. Such an analysis measures the percentage of carbon dioxide or oxygen, or both, and the results are expressed as the percent of excess air supplied for combustion.

The chemical reaction involved in burning natural gas may be written as:

$$CH_4 + 2O_2 + 7.5N_2 \rightarrow CO_2 + 2H_2O + 7.5\,N_2 + \text{Heat}$$

This equation says that if one volume of methane is perfectly mixed and burned with 9.5 volumes of air, the product will be hot flue gas consisting of one volume of carbon dioxide, two volumes of water vapor, and 7.5 volumes of nitrogen. If more than the required amount of air is used, the flue gas will contain some oxygen, and a larger amount of nitrogen than normal. Conversely, if insufficient air is used, the methane will not be completely burned and the flue gas will contain some carbon monoxide (CO).

If the fuel is coal or heavy oil it becomes difficult to achieve the perfect mixing of air and fuel vapor assumed in the above equation. In such cases, the flue gas may contain particles or droplets of partially decomposed fuel, resulting in fuel waste, visible smoke, and usually a rather large quantity of CO. In severe cases one can find unburned fuel, CO, and O_2 existing simultaneously in the flue gas. Thus, although gas can be burned with only 1 or 2 percent excess air, it is usually necessary to burn oil or coal with an excess of 10 to 15 percent.

The amount of air theoretically required for the combustion of different fuels [12], expressed as pounds of air per pound of fuel burned, is shown in table 9.

TABLE 9. *Air required for the combustion of some fuels*

Fuel	Theoretical air requirement, pounds of air per pound of fuel
Natural gas	17.3
Fuel oil (#2)	15.3
Heavy fuel oil	14.9
Propane	15.7
Coal	13 (approximate)

If a pound of natural gas is burned with 17.3 lb of air, it will produce 18.3 lb of flue gas which will contain no uncombined oxygen, i.e., there is no excess air.

If 100 percent excess air is used, the mass of flue gas will be (1+17.3+17.3) lb = 35.6 lb, and the oxygen content will be about 11 percent by volume.

The importance of controlling excess air is illustrated by calculating the stack loss for the above two cases, assuming a stack temperature of 1000 °F, and a heat of combustion of 23 500 Btu/lb.

At 0 percent excess air, the heat in the stack gas is:

$$H = 18.3 \text{ lb} \times 0.24 \text{ Btu/lb}\cdot{}^\circ\text{F} \times (1000-70)\ {}^\circ\text{F}$$

$$= 4085 \text{ Btu}.$$

The percent loss is :

$$\frac{4085\ \text{Btu}}{23\,500\ \text{Btu}} \times 100 = 17.4\ \text{percent.}$$

At 100 percent excess air, the heat in the stack gas is:

$$H = 35.6\ \text{lb} \times 0.24\ \text{Btu/lb}\cdot{}^{\circ}\text{F} \times (1000-70)\ {}^{\circ}\text{F} = 7945\ \text{Btu.}$$

The percent loss is:

$$\frac{7945\ \text{Btu}}{23\,500\ \text{Btu}} \times 100 = 33.8\ \text{percent.}$$

This method of calculation was used in setting up the curves in figure 2. It can also be used to extend the curves to higher values of excess air. The use of such curves or tables makes possible the simple calculating methods used in section 2.2, showing energy balances on a heat treating furnace.

When the quantity of excess air becomes very high, more than about 200 percent, one must revert to actual measurement of both fuel and air flows. This is because most of the instruments and methods for flue gas analysis were designed to achieve their maximum precision at or near 0 percent excess air.

Vendors of gas analysis equipment usually furnish curves or tables to translate instrument readings into percent excess air. Figure 14 is representative of this type of information assuming that no CO is present.

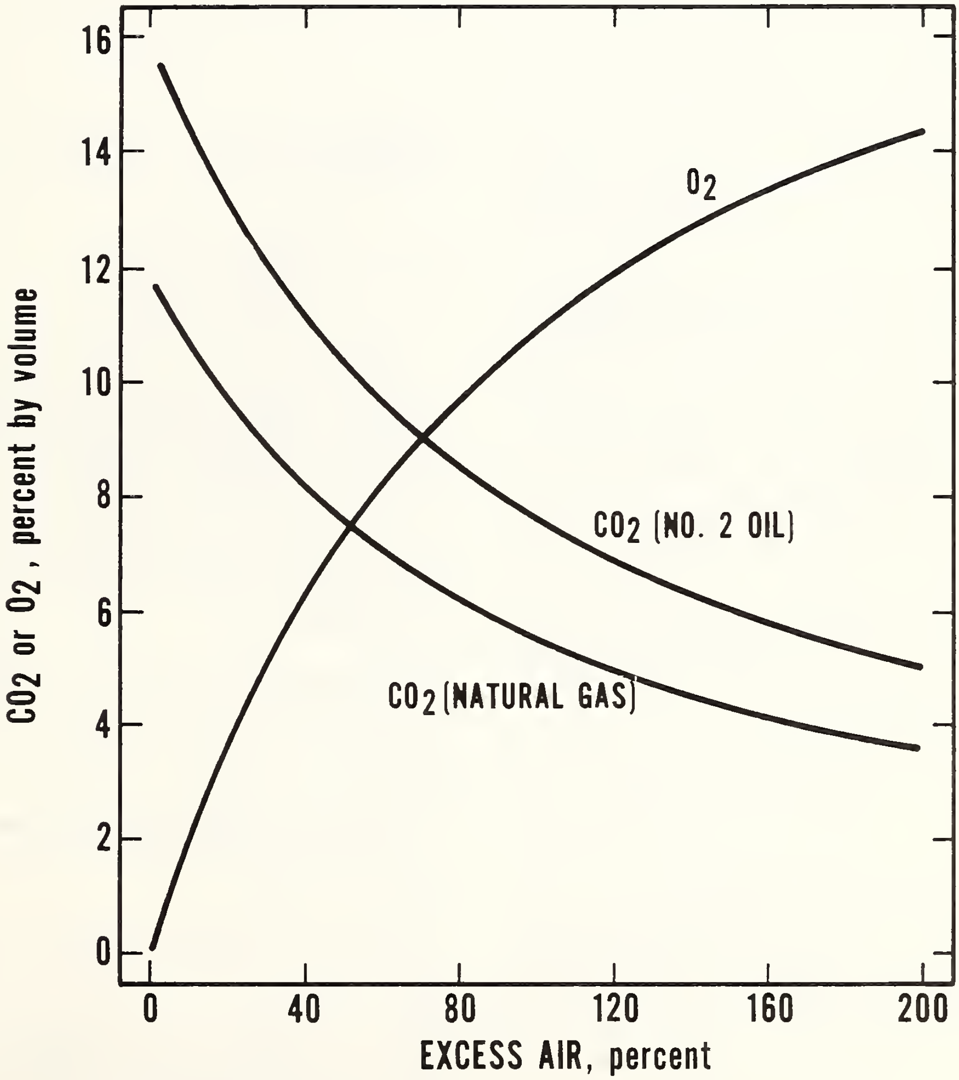

FIGURE 14. *Excess air determined from CO_2 and O_2 content of dry flue gas.*

A more accurate calculation of excess air can be made from the nitrogen content as determined by an Orsat analysis. Assume one is burning oil or gas and that unburned hydrocarbons are negligible. The Orsat analysis (sec. 5.4) gives us dry volume[9] fractions of N_2, O_2, CO_2, and CO in the stack gas. First, the composition should be adjusted to complete combustion: half the volume fraction of CO present should be subtracted from the volume fraction of O_2 to give a new effective O_2 fraction (this reflects the fact that if the CO were burned, half a volume of O_2 would be consumed for each volume of CO).

Each volume of effective O_2 brought in 79/21 volumes of nitrogen with it which were completely surplus. The ratio of this surplus nitrogen to the nonsurplus nitrogen is simply the excess air. Thus:

$$\frac{\frac{79}{21}(O_2-1/2\ CO)}{N_2-\frac{79}{21}(O_2-1/2\ CO)}\times 100=\text{percent excess air,}$$

where N_2 stands for the volume fraction of N_2 in the stack gas, etc.

4.6. Calculation of Mass Flow Rates for Gases

In calculating heat balances, it is more convenient to use mass flow rates instead of volumetric rates, or sometimes gas velocities, which are obtained by the usual methods of measurement (sec. 5). The conversion of these measurements to mass rates involves three steps:

(1) To convert gas velocity to volumetric flow rate, one merely multiplies the velocity by the cross sectional area of the duct. For example, if one measures an average velocity of 500 ft/min in a round duct 1.5 ft in diameter, the volumetric flow rate is:

$$500\ \text{ft/min}\times\frac{\pi(1.5)^2\ \text{sq ft}}{4}\times 60\ \text{min/h}$$

$$=53\,000\ \text{cubic feet per hour (cfh).}$$

(2) The volume rate should then be converted to standard temperature and pressure, 60 °F and 30 inches of mercury (406.5 inches of water or 14.7 psi). According to the gas laws:

$$V_s=\frac{PVT_s}{P_sT}$$

where

P = absolute pressure of the gas being measured,
V = volume of the gas (or volume flow rate),
T = absolute temperature of the gas (°F+460), and
P_s, V_s, T_s = pressure, volume, and temperature at standard conditions.

In most of the cases under consideration here, the value of P will be the same as P_s within about 2 percent (8 inches of water or 0.3 psi), and the pressure terms can be neglected. In such cases,

$$V_s=\frac{VT_s}{T}.$$

If, in the example above, the measured temperature was 500 °F, then

$$V_s=\frac{53\,000\ \text{cfh}\times(60+460)}{(500+460)}$$

$$=28\,700\ \text{standard cubic feet per hour (scfh).}$$

If the gas pressure is much above atmospheric, say more than 1 psig (pounds per square inch—gage), the pressure terms should be included in the calculation. Note that the pressures may be in any convenient units as long as both pressures are expressed in the same units, and that they must be absolute pressures, i.e., referred to a vacuum and not to the local atmospheric pressure.

(3) The final step is to convert to a mass flow rate by multiplying the standard volumetric rate by the gas density. Table 10 lists the density of some of the common gases at standard conditions [1].

The density of a mixture of gases can be calculated if the analysis by volume is known or can be estimated. The formula is:

$$(a\times d_a)+(b\times d_b)+(c\times d_c)+\ldots=d_m$$

where

a, b, c, etc. = volume fraction of the different gases,
d_a, d_b, d_c, etc. = density of the different gases, and
d_m = density of the mixture.

---

[9] The water formed by burning H_2 is condensed during the sampling procedure.

Table 10. *Density of some common gases at standard temperature and pressure*

Gas	Density
	lb/scf
Air	0.0766
Oxygen	0.0846
Nitrogen	0.0744
Carbon monoxide	0.0740
Carbon dioxide	0.1170
Water vapor	0.0476
Natural gas (methane)	0.0425
Propane	0.1196
Hydrogen	0.0053
Acetylene	0.0697
Ammonia	0.0456
Dissociated ammonia	0.0228
Paint solvents	0.2 to 0.3
Flue gas (natural gas)	0.074 (approximate [a])
Flue gas (fuel oil)	0.077 (approximate [a])

[a] Assumes the presence of all of the water of combustion and 50 percent excess air. If the excess air is very large, as in a paint dryer, assume the same density as air.

For example, consider a moisture free gas for a controlled furnace atmosphere with an analysis as shown below:

	Fraction by volume		Density lb/scf	
CO_2 (carbon dioxide)	0.055	×	0.117	= 0.00644
CO (carbon monoxide)	0.09	×	0.0740	= 0.00666
CH_4 (methane)	0.008	×	0.0425	= 0.00034
H_2 (hydrogen)	0.15	×	0.0053	= 0.00080
N_2 (nitrogen)	0.697	×	0.0744	= 0.05185
Density of mixture = 0.0661 lb/scf				

If this mixture represents the gas in the previous example, with a volumetric flow of 28 700 scfh, the mass flow rate is:

$$28\,700 \text{ scfh} \times 0.0661 \text{ lb/scf} = 1897 \text{ lb/h}.$$

5. Methods of Measurement for Heat Balances

In previous sections it was pointed out that measurements of such items as fuel usage rate, temperatures, flue gas analysis, etc., are necessary for estimating a heat balance. Here we suggest methods of obtaining these necessary measurements. For a more detailed treatment of measuring methods the reader may consult references [1, sec. 9], [12], and [18].

5.1. Fuel Consumption

The ideal instrument for measuring the flow of gas or oil to a furnace is a positive displacement totalizing meter of the type used by fuel vendors. If such a meter is read once an hour, or even once a shift, the hourly fuel rate is readily calculated for the furnace on which the meter is installed. One meter can easily be used for several furnaces if appropriate pipe fittings and valves are installed in the fuel line to each furnace.

Flow rate indicators, such as orifice plates or rotameters, are usually less expensive than totalizing meters and may be adequate for measuring a flow rate that is steady over long periods of time. They are not satisfactory when the temperature control system is one which makes frequent large changes in the amount of fuel supplied. In such cases, a totalizing meter is essential. Flow rate indicators can be useful to assure that proper fuel distribution exists among the individual burners of a multi-burner installation. This requires, of course, an indicator installed on each individual burner.

Meters of any type should be sized for the job. For example, if a furnace uses 100 cfh of gas, a suitable meter should indicate amounts as small as 1 cf. If, on the other hand, the usage is 10 000 cfh, a minimum indication of 100 cf would be adequate.

5.2. Energy Input to Electric Furnaces

The instantaneous flow rate of electric energy to a resistance heater can conveniently be measured with a clamp-on ammeter. This instrument will measure the current demand in amperes if *one* of the wires to the furnace is surrounded by the spring loaded C-clamp which is part of the instrument. The flow rate (power) in watts is simply amperes times the applied voltage or, if multiple heating elements are wired into a 3-phase network, power is amperes times volts times the square root of three (1.732).

If the temperature control system is of the full on-off variety, one can measure energy by wiring an electric clock across the heater terminals to indicate the total turned-on time. For example, if after 8 hours of elapsed time the clock indicates 5.5 hours, and the heaters draw 15 kilowatts, the average energy usage rate is 15 kW×5.5 h/8 h=10.3 kW.

If the temperature is controlled by a throttling device, such as variable inductance transformers or silicon controlled rectifiers (SCR's), or if the furnace is heated by induction, one must use a recording kilowatt hour meter of the type used by the electric utility companies.

5.3. Temperature

For the temperature range of concern in this handbook, a thermocouple is by far the most convenient and satisfactory measuring device. Details of the various types of thermocouples and their application are well covered in the references already cited, as well as in manufacturer's literature.

Thermometers of either the bi-metallic or liquid filled variety may be less expensive. They are, however, limited to temperatures below about 800 °F, and can be inconvenient to read if the required location of the measurement is in a spot that is difficult to reach.

When the temperature to be measured is that of furnace flue gas, the temperature should be measured as near as possible to the point at which the gases leave the combustion chamber. If the measurement is made after the gas has been cooled, either by wall losses from duct work or by the infiltration of cold air, the resulting heat balance will be erroneous. If the flue gas is fed from the combustion chamber to waste heat recovery equipment such as a recuperator, a heat exchanger, or a waste heat boiler, temperature measurements should be made at both the combustion chamber exit and the exit from the heat recovery device. Both measurements are needed in order to assure that the heat exchanger is continuing to operate properly. Baumeister and Marks Handbook [12] explains these and other temperature measuring techniques.

5.4. Flue Gas Analysis

The Orsat analyzer, a selective absorption device, has long been considered the standard instrument for a flue gas analysis [19]. It analyzes separately for the following gases by volume:

- ○ Carbon dioxide (CO_2), an indicator of the amount of excess air, assuming complete combustion.
- ○ Carbon monoxide (CO), which, in amounts of more than about 0.1 percent, is an indicator of incomplete combustion.
- ○ Oxygen (O_2), a rather accurate indicator of the amount of excess air; its absence suggests incomplete combustion.
- ○ Nitrogen (N_2), which is not analyzed directly but is assumed to be the remainder of the sample.

Water is condensed during the sample preparation. Its amount in the hot flue gas can be estimated from the amount of excess air coupled with knowledge of the type of fuel used (see sec. 4.6 on density of gases).

Figure 15 shows in graphical form the changes in an Orsat analysis of the flue gas when burning natural gas with various air/fuel ratios. The curves were calculated from the combustion equations [2] and from data in reference [12].

A simpler and less costly gas absorption device than the Orsat (approximately $90 vs. $250 to $300) measures only one constituent, either CO_2 or O_2. Devices of this type are frequently used by maintenance men when adjusting home furnaces. If used, it is suggested that two of them be available to check for both CO_2 and O_2. This helps to detect errors in measurement. For example, if gas is the fuel, a measurement of 9.5 percent CO_2 should be accompanied by a measurement of 3.8 percent oxygen (see fig. 15). Any other combination indicates an error in measurement. If only one gas is measured, O_2 is preferred since its absence will indicate a condition of incomplete combustion.

In addition to the chemical absorption devices, there are several kinds of electronic instruments which can be permanently installed to monitor flue gas. A very useful instrument for large continuous furnaces (or boilers) uses either a paramagnetic or a zirconium oxide sensor for continuously indicating and recording the percentage of O_2. It gives an accurate and permanent indication of any changes in combustion conditions.

In all cases, the sample of flue gas to be analyzed should be taken as near to the combustion chamber as possible. If the gas has been diluted with infiltrated air, the analysis results will obviously be useless.

5.5. Gas Flow at Low Pressure

If the amount of excess air in a furnace or oven must be more than about 200 percent, the use of an Orsat analysis to calculate mass flow rate and stack loss becomes very inaccurate. One must resort, therefore, to direct measurement of the gas flows either at the air intake, in the stack, or at some other convenient point in the system.

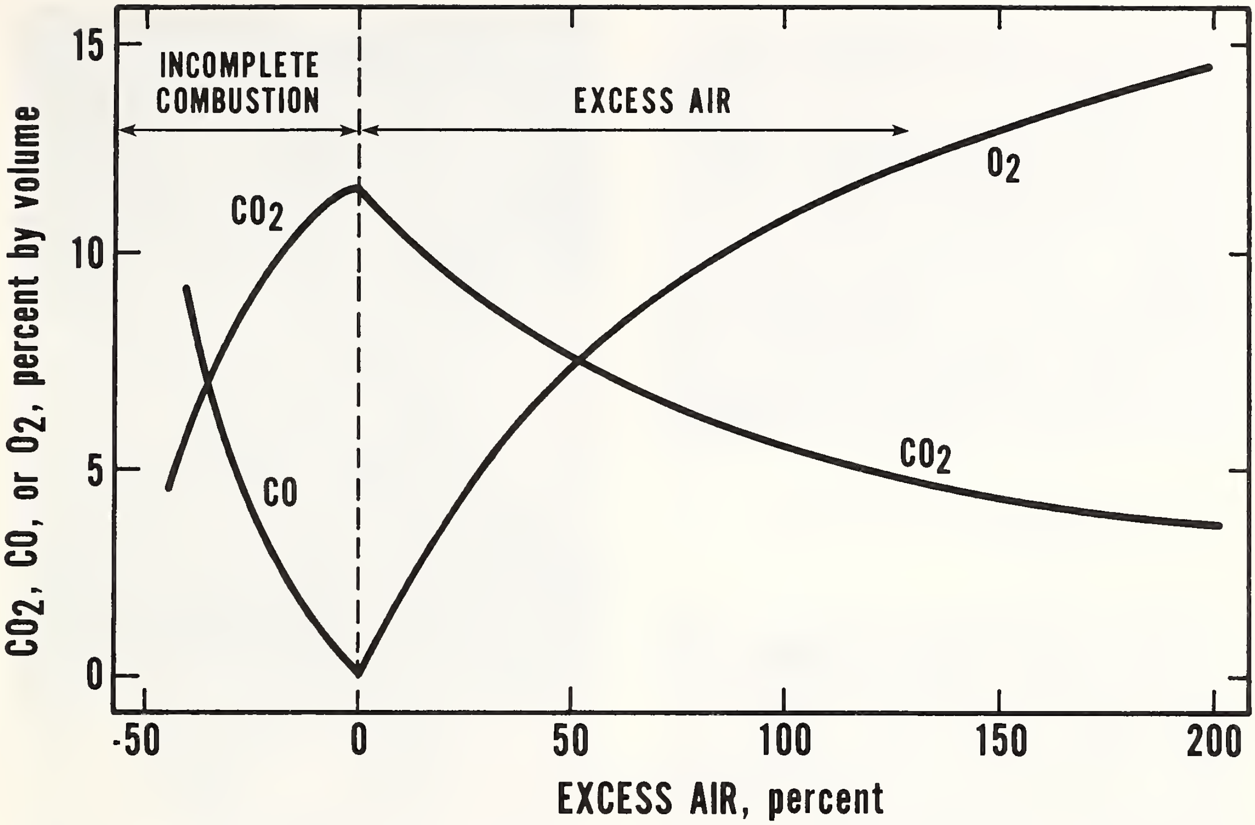

FIGURE 15. *Effect of excess air on flue gas analysis for combustion of natural gas.*

The flow meters mentioned in section 5.1 all cause some slight drop in pressure of the flowing fluid. They are not suitable for use in the combustion system, where pressure is typically only 1 to 4 inches of water. The choice of instruments, therefore, is rather limited. Some types that may be suitable include pitot tubes and anemometers.

The *pitot tube* actually consists of two tubes, one with an opening facing into the flow and one with an opening at a right angle to the flow. The difference in pressure between the two tubes is an indication of gas velocity. Pitot tubes may be used in ducts of 4 inches diameter or larger over a quite wide range of gas velocities and at temperatures limited only by the materials for tube construction. For best accuracy, there should be 10 diameters or more of straight duct before and after the pitot tube location.

A *hot wire anemometer* indicates gas velocity by measuring the cooling effect of a gas stream on an electrically heated wire. Hot wire anemometers are available as either fixed or portable instruments. They are limited in the temperature at which they can operate: 250 °F is a normal upper limitation.

Mechanical anemometers utilize a fan or a turbine whose rotational speed is a function of the velocity of the driving fluid. Depending on the application, e.g., hand held instruments for room air velocity measurement or models for permanent installation in a pipeline, their cost and complexity vary widely. They are, for mechanical reasons, usually confined to temperature ranges below about 200 °F.

In general, all of these devices are subject to major errors if they are allowed to collect gummy materials or particulate matter. Under such conditions, one must clean the instruments quite frequently to obtain accurate measurements.

6. Different Types of Furnaces, Kilns, and Ovens

The principles of obtaining the measurements and performing the calculations for a heat balance are exactly the same for each type of industrial heating equipment. They are to identify and to measure or estimate all the quantities of energy entering and leaving the equipment. In this sense, the job is the same whether the equipment is called an electric box hardening furnace, a bell furnace, a brick kiln, or a continuous bakery oven. There are nonetheless detailed differences in the best approach to the job, depending on the specific type of equipment.

6.1. Direct Fired Furnaces

Direct fired furnaces are those in which the products of combustion (the flue gas) come into direct contact with the product being heated. They may be subdivided into batch and continuous furnaces.

a. *Batch direct fired furnaces* include the following commercial types:

Box furnaces (fig. 16)
Car bottom furnaces (fig. 17)
Pit furnaces (fig. 18)
Bell furnaces (fig. 19)
Rotary retorts (some of them).

Such furnaces may be further classified according to their intended use, such as brazing, drawing, hardening, forging, etc.

The example in section 2.2 illustrates a heat balance on this type of furnace. Specific items to watch for, in addition to air/fuel ratio, adequate insulation, and waste heat recovery, include:

○ Frequent opening and closing of the furnace, which often results in leaks around gaskets or seals and energy losses by cold air infiltration. This can be particularly important in the seals around the edges of a car bottom furnace. Regular inspection and maintenance is called for.

○ Air infiltration through unavoidable leaks can be prevented or minimized by installing an automatically controlled flue damper to maintain a slight positive pressure in the furnace chamber. More details are given in section 3.

○ An obvious source of energy loss with a batch furnace is the heat which escapes during the unloading and reloading period between batches. The extent of the loss may be measured by metering the fuel flow from the time the door is opened for unloading until it is closed on the new load and the next cycle started. While this loss is not treated in detail in the heat balance in section 2.2, it obviously must be considered in calculating overall fuel usage per unit of product.

○ A single batch cycle will use less energy if the furnace walls are relatively hot when the cycle starts; hence the door open time between batches should be held to the minimum. See section 3 for more details.

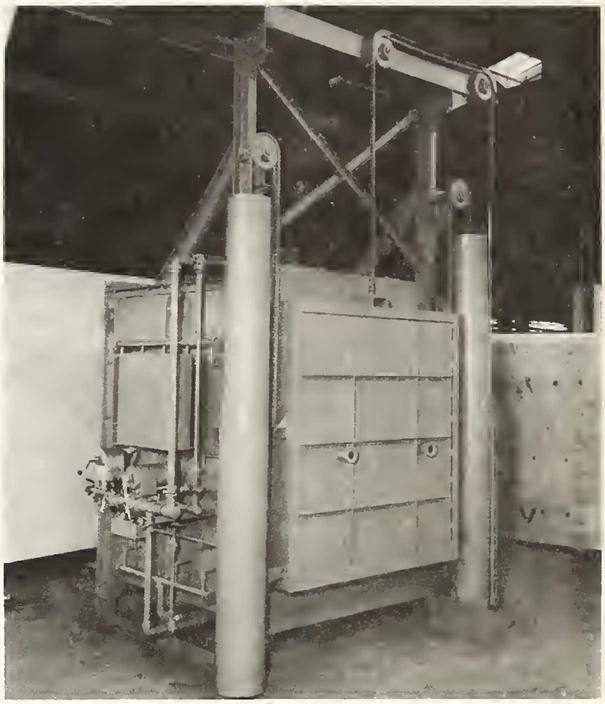

Figure 16. *A gas fired box furnace.*
Courtesy of American Gas Furnace Co.

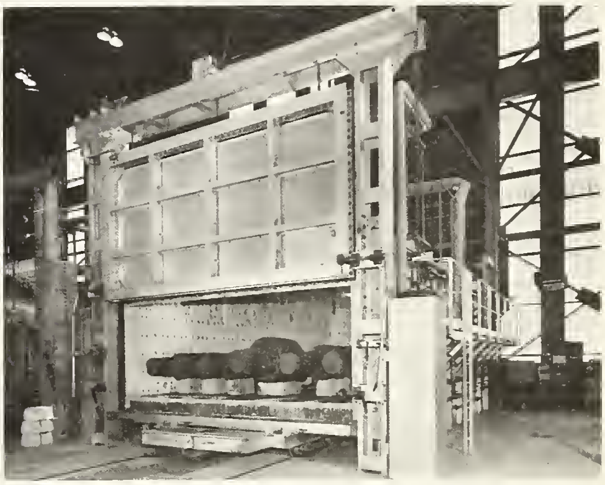

Figure 17. *A car bottom furnace with ceramic fiber insulation.*
Courtesy of Olson Industries Corporation.

b. *Continuous direct fired furnaces* are those through which product is fed and removed in either a continuous or intermittent fashion; i.e., there is no distinct batch. Commercial designations include:

Belt furnaces

Roller hearth furnaces
Rotary hearths (fig. 20)
Shaker hearths (fig. 21)
Slot (forging) furnaces
Pusher furnaces
Rotary retorts (some of them).

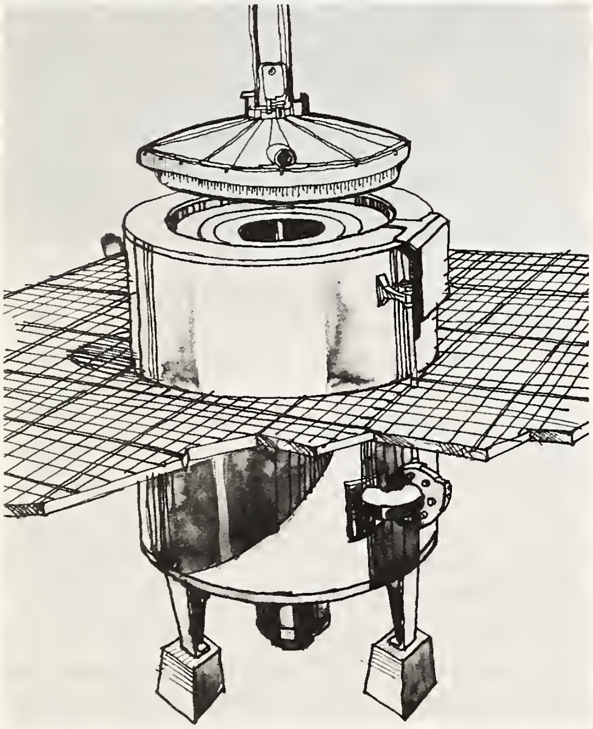

FIGURE 18. *An electrically heated pit furnace.*
Courtesy of Leeds and Northrup Co.

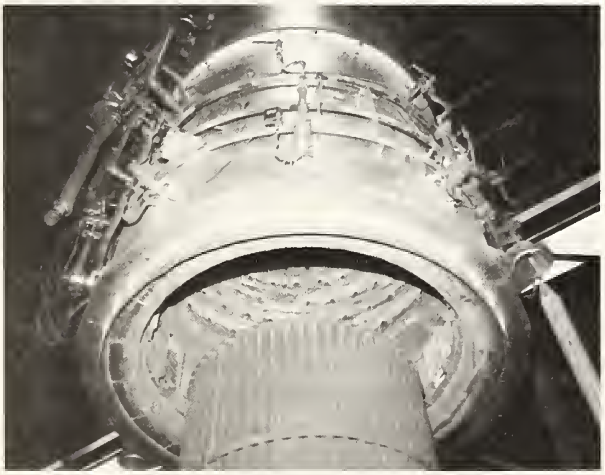

FIGURE 19. *A bell, or pedestal, furnace.*
Reprinted from INDUSTRIAL HEATING, February 1975.

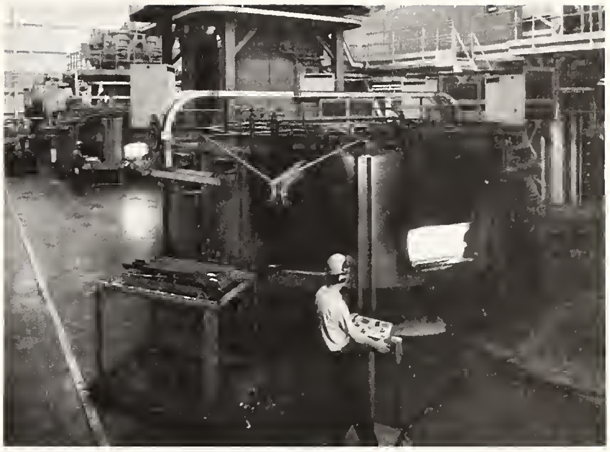

FIGURE 20. *A rotary hearth furnace, electrically heated, with endothermic gas atmosphere.*
Courtesy of Flynn and Dreffein Engineering Co.

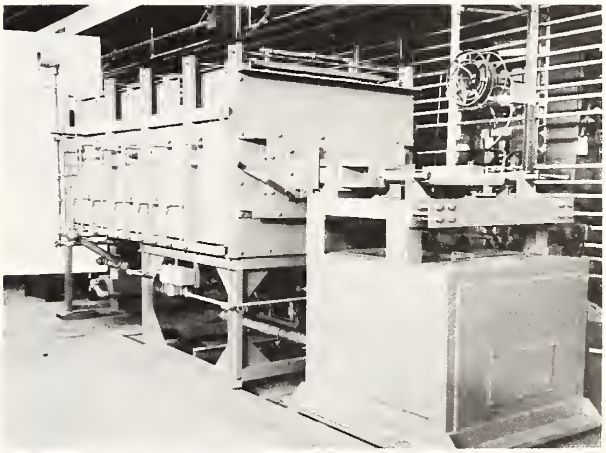

FIGURE 21. *A shaker hearth furnace.*
Courtesy of American Gas Furnace Co.

A heat balance for a continuous furnace is essentially the same as a batch furnace, section 2.2. Following are some of the special considerations involved:

○ Since there is no batch cycle time, measurements and calculations should be made on the basis of some specific time interval such as an hour or a shift. Ideally, heat balances should be made both at idling conditions (no load), and at design conditions (full load). Fuel use at partial loads can be estimated from these data.

○ Since access ports for the charging and removal of product are open either all or most of the time, energy loss because of the openings is more important than in a batch furnace. A slight positive pressure in the furnace is recommended. See section 3 for a more detailed discussion of draft control.

○ Losses by radiation through open ports can be large, and might well be considered as a separate energy loss in the heat balance. A method of estimating radiation loss is given in section 3. It is obvious that such openings should be as small as practical.

○ In some continuous furnaces, the material handling equipment (belt, rollers, etc.) is all within the hot zone. In others, however, a belt may leave the hot zone and return at room temperature. In such cases, the energy required to reheat the belt to operating temperature should be considered as a loss (energy output) in calculating the heat balance.

6.2. Indirect Fired Furnaces

Indirect fired furnaces are those in which the combustion gases do *not* come into contact with the product. This may be merely to protect the product from local overheating, but more frequently the reason is to permit careful chemical control of the furnace atmosphere (e.g., oxidizing, reducing, neutral, carburizing, etc.).

Such furnaces may be batch or continuous in operation. They may be any of the mechanical designs listed under direct fired furnaces (box, pit, bell, roller hearth, etc.). They may be categorized in addition as:

Muffle furnaces
(Controlled) atmosphere furnaces
Radiant tube furnaces
Carburizing furnaces (fig. 22)
Carbonitriding furnaces
Salt pots.

These various methods of categorizing can give rise to such labels as a "box type, radiant tube, controlled atmosphere, hardening furnace."

a. An indirectly fired furnace *without controlled atmosphere,* having atmospheric air in contact with the product, can be treated in almost exactly the same way as an equivalent direct fired furnace from the point of view of a heat balance. There are two minor exceptions:

○ If outside air is deliberately drawn through the product chamber, e.g., to cool the product before discharge from the furnace, the volume and the exit temperature of this air must be measured and its heat content must be added to the output side of the heat balance.

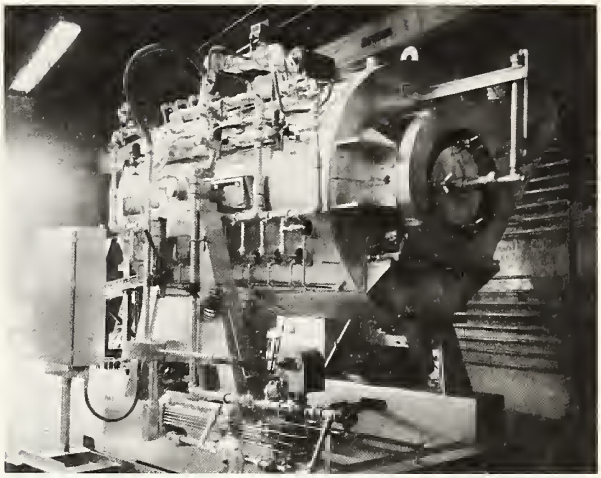

FIGURE 22. *A batch type rotary carburizer.*
Courtesy of American Gas Furnace Co.

○ If air is not circulated through the product chamber, i.e., if the chamber is closed as tightly as possible, there will be little tendency towards air infiltration as is the case in direct firing.

b. In a furnace *with controlled atmosphere,* the product chamber is flushed free of air with some special gas and gas continues to flow during the firing cycle to maintain a slight positive pressure. The energy flows due to this controlled atmosphere should be accounted for.

In calculating the heat balance one should consider the gas generator as part of a single system along with the furnace itself and treat the energy used by the generator per hour or per cycle as one of the energy inputs. Since only a very small percentage of the atmosphere will actually combine with the product, this same amount of energy should appear as a waste heat output.

The following list, (1) through (7), indicates methods of calculating the heat content of different types of furnace atmospheres.

(1) For exothermic generator gas, the energy content should be considered as the fuel value of the natural gas furnished to the generator (1000 Btu/cf).

(2) For endothermic generator gas, the energy content is the fuel value of the gas charged, including that which is used for external heating of the generator tubes.

(3) Dissociated ammonia has a fuel value of 16 000 Btu/lb (490 Btu/scf), plus the energy used in heating to the dissociation temperature.

(4) If any of the above gases are conditioned by the removal of water vapor and/or carbon dioxide, the energy for this conditioning must be added as part of the system input.

(5) Pure hydrogen has a heating value of 61 100 Btu/lb (325 Btu/scf).

(6) Nitrogen, liquid or in pressure tanks, has no heating value.

(7) Propane, used in preparing enriched gas, has a heating value of 22 000 Btu/lb, 91 000 Btu/gal, or 2500 Btu/scf.

The need to meter gas to an atmosphere generator is implied by the preceding paragraph. If a central generator is used to furnish the atmosphere gas for a group of furnaces, it may be adequate to meter material to the generator and estimate its allocation to the individual furnaces.

c. *Special types* of indirect fired furnaces include:

(1) *Salt pots.* A salt pot, or a fused salt bath, is a special type of indirectly fired controlled atmosphere batch furnace. In calculating a heat balance it may be treated like a direct fired batch furnace with, usually, a quite short cycle time. The exception is the need to determine the amount of replacement salt charged per cycle, to calculate the energy needed to melt the salt and raise it to operating temperature, and to list this energy as a heat output.

The radiation loss from the open surface of a salt pot may be significant. It should be estimated and listed as an output in the heat balance. (See sec. 3.4 for method of estimating.)

(2) *Pack carburizers.* Pack, or box, carburizing is technically an indirect fired, controlled atmosphere operation which is usually performed in a batch type direct fired furnace.

The energy required to heat up the carburizing box and all of its contents is part of the output in a heat balance.

The fuel value of the carburizing material, charcoal for example, is added to the input side of the heat balance. If a portion of the charcoal is recovered for re-use, one need only consider the new charcoal added for each batch.

To conserve energy, the tare weight of the box per pound of product, as well as the amount of carburizing material used, should be as low as is practicable.

(3) *Recirculating furnaces.* Recirculating fans or blowers act to mix or stir the furnace atmosphere. They promote a more uniform temperature, can increase the rate of heat transfer to the product, and can permit the use of lower temperatures.

Since recirculating systems are designed to neither add nor subtract energy from the furnace, they can be generally ignored in calculating a heat balance. Portions of the recirculating system outside of the heated zone can contribute to the energy losses due to radiation and convection. Outside ducts and fan housings should be well insulated.

6.3. Dryers

Dryers can be defined as heating equipment for the purpose of driving off volatile materials such as water or organic solvents. They may be either batch or continuous in operation. The common name of a dryer will usually refer to the product being treated:

Paint drying oven
Ceramic drying kiln (fig. 23)
Lumber kiln
Continuous bakery oven
Rotary retort parts dryer
Etc.

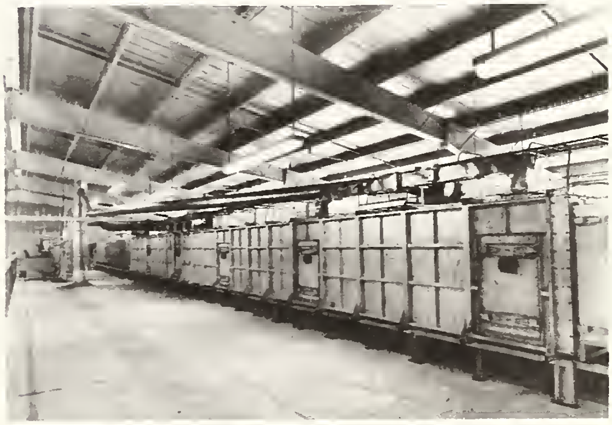

FIGURE 23. *A kiln for the drying and curing of automobile exhaust control catalyst.*
Reprinted from INDUSTRIAL HEATING, September 1975.

An example of a heat balance on a continuous paint drying oven is shown in section 2.3.

Dryers are usually operated at low temperature (150 to 500 °F). In spite of the low temperature, heat losses by radiation and convection from walls and ceiling can be very important, since the wall and ceiling areas tend to be rather large and cycle times may be lengthy.

Dryers are often operated with rather large quantities of excess air (200 to 1000 %) to promote rapid drying and to prevent forming an explosive atmosphere if the solvent is combustible. If the excess air is above about 200 percent, a flue gas analysis becomes very inaccurate and direct measurement of air or flue gas flow rate is necessary to calculate the stack losses. Obviously, the amount of excess air should be no greater than is required by the demands of the process. For a method of reducing the amount of diluent air in paint drying, see reference [4].

If the solvent being evaporated is combustible, the fuel value (heat of combustion) must be added to the input of the heat balance.

Air pollution regulations generally require that hydrocarbons such as paint solvents be removed before any gas stream is exhausted to the atmosphere. This can be done by a variety of means, the most common one being to burn more fuel with the stack gas and raise its temperature to about 1600 °F. Whatever the method, this clean-up operation must be considered as an integral part of the system, and all the energy added at this point is an energy input to the heat balance. Special attention should be given to the means of recovering this heat and if possible returning it to the system (see sec. 3).

Dryers are sometimes part of a more complex system. For example, in a continuous brick kiln there can be different zones to drive out water, to increase the temperature slowly to the firing level, to fire the bricks, and to cool at a controlled rate. This may be accomplished with multiple air inlets and by exhausting gases at more than one point. To calculate a heat balance, one should first treat the complex as a single system and consider only the energy and material flows which enter and leave it. If necessary, one can then estimate energy balances for a single part of the system such as the drying zone.

6.4. Electric Furnaces

Any of the types of furnaces, kilns, or ovens discussed in the previous paragraphs can be heated electrically instead of by directly burning fossil fuels. There are only a few special items to consider in making a heat balance.

Since there are no fuel combustion products, there is no stack loss in the usual sense. If the application is to a dryer or to a controlled atmosphere furnace, one must, of course, consider the energy flows associated with the drying air or with the special furnace atmosphere.

A heat balance on an electric furnace, using a conversion factor of 3412 Btu/kWh, will normally show a lower heat input than is required by an equivalent furnace fired by gas or oil. The relatively high cost of electricity (sec. 7) will frequently outweigh the apparent saving.

If one wishes to compare a gas or oil fired furnace with its electrical equivalent on the basis of fossil fuel burned instead of cost, a kilowatt hour should be valued at 10 000 to 12 000 Btu. This is the value of the fuel burned by a generating station to produce one kilowatt hour of electricity worth 3412 Btu for furnace heating. The power plant loss is reflected in the cost of electricity.

7. Financial Considerations

The previous sections contain some suggestions for energy saving which will require the investment of capital dollars in order to achieve savings. In some cases the savings per year may be so large, and the capital cost so small, that the desirability of the project is obvious. In other cases, a more detailed analysis is needed.

This section discusses two of a number of procedures for making a financial analysis of your cost saving opportunities. An important factor in your analysis is the amount you are paying for your energy.

The reason for determining energy costs is to allow you to make a valid analysis of the actions you might need to take to save energy and money. The cost varies widely with the fuel source used. Table 11 shows the cost of energy at various fuel and electricity prices. The energy costs listed assume that all of the energy content of the fuel is used, i.e., that there are no losses or inefficiencies. In actuality, there are losses, and efficiency is usually less than 100 percent. For example, in space heating with oil or gas, some of the heat is lost out the furnace stack. This results in a range of efficiency of 50 to 85 percent, with 60 percent being an average figure. Thus, if oil at $0.42 per gallon is used for space heating at an efficiency of 70 percent, the actual cost per MBtu delivered as useful heat is $3.00 divided by 0.70, or $4.29 per MBtu. Note that electricity is by far our most expensive form of energy. But of course, it is also our most convenient and efficient form and has no replacement for some applications.

TABLE 11. *Energy cost resulting from various fuel or electricity prices*

Fuel or electricity prices					Resulting energy cost
Electricity	Oil	Gas	Propane	Coal	
$/kWh	$/gal	$/1000 cf	$/gal	$/ton	$/MBtu[a]
0.0034	0.14	1.00	0.092	28.00	1
0.0068	0.28	2.00	0.183	56.00	2
0.0102	0.42	3.00	0.275	84.00	3
0.0136	0.56	4.00	0.366	112.00	4
0.0171	0.70	5.00	0.458	140.00	5
0.0205	0.84	6.00	0.550	168.00	6
0.0239	0.98	7.00	0.641		7
0.0273	1.12	8.00	0.733		8
0.0307		9.00			9
0.0341		10.00			10
0.0512					15
0.0682					20
0.0853					25
0.102					30

[a] One MBtu equals one million Btu.

7.1. Benefit/Cost Analysis

The benefit/cost analysis can be used to decide if a capital investment is economically justified, or it can be used as a basis to choose between several alternatives after a decision to invest has been made. First, all benefits and all costs are reduced to a dollar value, and the ratio of benefits to costs is taken. If the ratio is greater than unity, the project may be economically justified and should be more fully examined.

Example: A heat recovery unit for a small heat treating plant costs $55 000 installed. It is estimated that the unit will save $12 000 annually in fuel and have a life of 10 years. Annual maintenance costs will be $500. The benefit/cost ratio is determined as follows.

Benefit:

$12 000 − $500 = $11 500 per year.

Cost:

Assume money is available at 10 percent interest. The annual cost will be the amortization cost, or annual payment required to repay the debt at 10 percent interest in 10 years. This is found by multiplying the total loan by a capital recovery factor, F (table 12).

TABLE 12. *Capital recovery factor*

Years	Capital recovery factor, F, for interest rate of				
	6%	7%	8%	10%	12%
5	0.2374	0.24389	0.25046	0.26380	0.27741
10	0.1359	0.14238	0.14903	0.16275	0.17698
15	0.1030	0.10979	0.11683	0.13147	0.14682
20	0.0872	0.09439	0.10185	0.11746	0.13388
25	0.0782	0.08581	0.09368	0.11017	0.12750
30	0.0726	0.08059	0.08883	0.10608	0.12414
40	0.0665	0.07501	0.08386	0.10226	0.12130

Thus, for an interest rate of 10 percent for 10 years, F=0.1628, and cost=$55 000×0.1628=$8954, and benefit/cost ratio=$11 500/$8954=1.28. The investment is profitable since the benefit/cost ratio is larger than unity.

Example: It has been decided by a small manufacturing company to make a capital investment in a waste-water heat recovery unit. Two systems are available:

System A:

Total cost	$14 000
Annual operation and maintenance costs	$900.

System B:

Total cost	$12 000
Annual operation and maintenance costs	$1400.

Both systems reduce energy utilization by the same amount, and both systems have estimated lives of 15 years. Money is available at 10 percent. Which system should provide the greater long term savings?

Net benefit per year of system A over system B = $500.

Additional cost of system A over system B=$2000.

For 10 percent interest rates over 15 years, the capital recovery factor, F, is 0.1315 (from table 12). Thus, the cost per year for the additional \$2000 of capital investment is:

$$\text{Cost} = \$2000 \times 0.1315 = \$263$$

and

$$\text{Benefit/cost} = \$500/\$263 = 1.90.$$

Although the original cost of system A is 16.7 percent more than system B, system A will provide the greater long term savings over the life of the system.

7.2. Time Required to Recoup Investment

Another approach is to determine how long it will take to recoup the investment required to accomplish a particular energy (dollar) savings. It is assumed that the annual savings is used to pay off the required loan at the current interest rate. If the investment is recouped in a period less than the life of the equipment, the investment is considered profitable. Table 13 can be used to estimate the time to recoup investment.

TABLE 13. *Time to recoup investment*

Investment/ savings ratio	Time to recoup investment at interest rate of			
	6%	8%	10%	12%
	Years	Years	Years	Years
2	2.19	2.27	2.34	2.42
3	3.41	3.57	3.74	3.94
4	4.71	5.01	5.36	5.77
5	6.12	6.64	7.27	8.08
6	7.66	8.50	9.61	11.2
7	9.35	10.7	12.6	16.2
8	11.2	13.3	16.9	28.4

Example: It has been estimated that an investment of \$20 000 is required to update the air-conditioning, heating system equipment, and controls installed in an older five-story office building. The life of the system will be extended for ten years. The annual savings in energy purchased plus reduced maintenance cost should be approximately \$5000. Money is available at 10 percent interest. To find the time required to recoup the investment, the following ratio is calculated:

$$\text{Capital investment/annual savings} = \$20\,000/\$5000 = 4.0.$$

Referring to table 13, at an investment/savings ratio of 4 and an interest rate of 10 percent:

$$\text{Time to recoup investment} = 5.36 \text{ years.}$$

This is less than the extended life of the system, so the investment would be profitable. These examples of cost analysis do not take into account some important considerations such as the value of spending the money in some other way or the impact of the state, local, and Federal taxes.

It is recommended that if an investment of any significant size is being considered, you conduct some detailed analysis of the life-cycle costs. One publication which addresses this subject in considerable detail is listed as reference [9], NBS Handbook 121.

8. Sources of Assistance

During both the planning and the execution of an energy management program you may well develop a lengthy series of questions to which you need answers. Some of the answers may be in the literature referenced in this handbook. The purpose of this section is to suggest sources of further information and assistance.

8.1. Private Consultants

Private consultants are available in almost all parts of the country. A local professional engineer familiar with energy problems can suggest equipment and instrumentation best suited to your particular situation. As an “outsider”, he will tend to see conservation opportunities which you may have missed because of long familiarity. Professional engineers are usually listed in the classified part of the telephone directory, or lists may be obtained from state or local chapters of a professional engineering society. The consultant’s fee may seem large, but if you are prepared with specific problems to be solved, his services may be well worthwhile.

8.2. Utility Companies

Utility companies and fuel suppliers frequently have ongoing programs to help their customers in achieving better energy management. Their services can range from suggestions for better operational techniques to major assistance in selecting proper meters for tracing energy use to selecting specific pieces of equipment.

8.3. Trade Associations

Trade associations often have survey information available covering energy usage in businesses which are the same as, or similar to your own. Such information can help you judge whether your energy costs are higher or lower than the average in your type of business. Some associations are also conducting energy conservation workshops.

Trade magazines also are valuable sources of information, both in articles on energy conservation and in advertisements for new equipment and instrumentation. The time spent scanning and reading them can be productive.

8.4. Government Organizations

Government, both at the State and Federal levels, can provide information and guidance on energy related problems. Most local governments can provide names and offices to contact in their respective organizations.

On the Federal level, the Department of Commerce, the Department of Energy, and the Small Business Administration can offer a great deal of assistance to industry. There are numerous publications available, many of which are free.

For information about Department of Energy programs and assistance, write:

Office of Conservation and Solar Environment
Department of Energy
Washington, D.C. 20542

Both the Department of Commerce and the Department of Energy maintain a network of field offices which are sources of assistance and information. The locations of these offices are listed in Appendices A and B.

9. Interaction with OSHA and EPA Requirements

Almost all industry and commerce today must be aware of the safety and environmental requirements and standards issued by the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) and by the Environmental Protection Agency (EPA). Attempts to meet these requirements in your business may in some cases conflict with energy management concepts. In most cases, they are compatible.

Energy management actions that involve reductions in ventilation may or may not be counter to health and safety regulations. Minimum requirements for ventilation air flow rates to remove odors, contaminants, smoke, dust and abrasive particles, flammable or combustible materials, etc. must be strictly observed. However, it has been found that actual ventilation rates often far exceed minimum requirements. Sometimes, ventilation is provided continuously whether the process requiring ventilation is operating or not. Excess energy usage in such cases usually can be eliminated without danger to safety or health.

When large quantities of warm contaminated air must be exhausted from a building during the heating season, the exhaust air can, by the use of a heat exchanger, preheat fresh outside air taken into the building. Conversely, during the cooling season, warm outside air brought into the building can be partially cooled down with colder exhaust air.

Heating and lighting in industry have not been regulated by OSHA, but OSHA has implied that employee efficiency and comfort must be satisfied. It is well known that many buildings are kept too warm for the majority of people, and thus energy is wasted. Lighting is often inefficient, and can be replaced by improved lamps and fixtures which use less energy and still provide satisfactory illumination.

Meeting air emission standards and anti-pollution requirements established by EPA can involve large capital investments. In many cases, pollution control projects can be economically justified by combining the solution with an energy management concept that reduces energy usage. Sometimes, combustible fumes that cannot be released to the environment can be burned and the released heat can be recovered and used for producing low pressure steam or hot water for heating, cleaning, etc. Many industries have found that wet or dry scrubbers necessary to meet exhaust gas emission standards allow them to burn natural gas, coal, oil, and waste products such as paper and sawdust.

The energy coordinator should be familiar with and have copies of the OSHA and EPA regulations [20] [21]. In questionable or involved situations professional assistance from a consultant may be necessary.

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Appendix A

U.S. DEPARTMENT OF COMMERCE DISTRICT OFFICE DIRECTORY

OFFICE OF FIELD OPERATIONS

August 1977

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Birmingham—Gayle C. Shelton, Jr., Director, Suite 200-201, 908 South 20th Street, 35205, Area Code 205 Tel 254-1331, FTS 229-1331

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•**Frankfort (Memphis, Tennessee District)**—Capitol Plaza Office Tower, Room 2332, 40601, Area Code 502 Tel 875-4421

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•**Grand Rapids**—17 Fountain Street N.W. 49503, Area Code 616 Tel 456-2411/33 FTS 372-2411

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Appendix A.—Continued

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III	1421 Cherry St—Rm 1001 Philadelphia, Pennsylvania 19102	(215) 597-2890
IV	1655 Peachtree St., N.E. 8th Floor Atlanta, Georgia 30309	(404) 526-2837
V	175 West Jackson Blvd Room A-333 Chicago, Illinois 60604	(312) 353-8420
VI	P.O. Box 35228 2626 West Mockingbird Lane Dallas, Texas 75235	(214) 749-7345
VII	Twelve Grand Building P.O. Box 2208 112 East 12th Street Kansas City, Missouri 64142	(816) 374-2061
VIII	P.O. Box 26247—Belmar Branch 1075 South Yukon Street Lakewood, Colorado 80226	(303) 234-2420
IX	111 Pine Street Third Floor San Francisco, California 94111	(415) 556-7216
X	1992 Federal Building 915 Second Avenue Seattle, Washington 98174	(206) 442-7280

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WASHINGTON, D.C. 20234

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This handbook, part of the EPIC Energy Management Series, is directed to the user of direct-fired heating equipment in light industry. Other publications in this series outline steps to plan and establish an energy conservation program in a business or industry. This handbook is a guide to making decisions as to just what actions are appropriate and effective for energy savings in equipment such as furnaces, kilns, and ovens. The major technique described is the heat balance. Examples of heat balances are used to identify energy losses on a batch furnace, a continuous paint dryer oven, and a slot forging furnace. Typical energy conservation opportunities in combustion control, insulation, etc. are discussed. Simplified methods of calculation and measurement are given. Benefit/cost analysis and the time required to recoup investment are described as means of evaluating energy-saving investments.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Energy conversation, industrial; furnaces, energy conservation; heat balance; industrial energy conservation; kilns, energy conservation; ovens, energy conservation.

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